Geology and mineralisation of the Mangani area, West Sumatra, Indonesia

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Abstract

The geology and mineralisation of the area around the disused Mangani gold mine have been investigated, in order to discover the mode of formation of the deposits.

Mangani lies in an eastern, inactive part of the dextral Sumatra Fault System (SFS), which formed as a result of oblique subduction of the Indian plate under the Asian plate. Mineralisation occurs in or near a graben, which in the NE joins with an active strand of the SFS. Veins are located in faults related to movement along the SFS, and to extensional movement in the Mangani Graben.

The geology of the area consists of marginal facies of the Central Sumatra Basin in the north, and a sedimentary breccia (Brani conglomerate) to the south. Basic to acid volcanics fill the graben, and lie on top of the sedimentary units, some volcanism being post mineralisation. Small intrusive bodies may be the exposed parts of a larger acid pluton.

Geological mapping and stream and soil geochemistry have resulted in the discovery of several new mineralised areas. One area has been examined in detail using soil geochemistry and geophysics (VLF, S.P, Turam, magnetics). The most important discovery has been a large area of completely unexposed lead/zinc mineralisation. The suitability of the different exploration methods for use in tropical mountain terrain is discussed.

Mineralogical examination and chemical analysis of specimens has revealed a complex history of fault controlled mineralisation. The vein mineralisation can be divided into a number of different groups, partly related to the geographical location and host rock type. Vertical zonation in veins is considered to be responsible for the spatial zonation.

Other mines in Sumatra appear to be similar to Mangani (hosted in volcanics, in faults related to the SFS, with similar suites of minerals), and a model for the formation for such deposits is proposed.

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I would like to thank all those people who made this work possible, especially the Indonesian Geological Survey, Directorate of Mineral Resources (DMR). Without the help of the Directer, Ir Salman, and the heads of the geochemistry and geophysics sections, Dr Thaib, and Ir Noer, work in Sumatra would not have been possible at all. DMR provided all logistic support during my first two visits to Mangani.

During my first visit to Mangani Endang Suganda from the geochemistry section was my counterpart, and coped heroically with introducing me to the complexities of field work in Indonesia.

On my second visit to Indonesia, when the first part of the geophysical work was done, Adang Muchlis from the exploration geophysics section of DMR organised all the logistic details, and together with Adrian, Bangiel Eragie, Budiman and Budi Gunardi did much of the work, while Udin, the cook, guarded the camp.

CSR Ltd provided logistic support for the last of the three field seasons, with the senior geologist in charge of the Mangani project (Reg Gerstelling) being very helpful. As well as organising my work for me, Gerry Wade and his wife provided accomodation in Bukittinggi, with fantastic meals, and Mardi helped sort out the logistic details.

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Last but not least I would like to thank the staff at Chelsea College, who were always willing to help. Dr Barber my supervisor, and Professor Blundell were always ready to critically read anything I had written, and provided much useful advice. Dr Woolrich and Dr Barber both also visited Mangani, guiding me in this work. Dr Alderton answered my questions about minerals, while Malcolm, Ray, and Neil cut great thin sections from horribly crumbly rocks. Gerry Ingram helped me with geochemical analyses, and Jane and Christine helped with cartographic and photographic problems. Susie Morrow and Martin Lailey were particularly helpful during the final panic stage of thesis preparation.

John Bowles and Don Aldiss (members of staff from IGS in Britain) also made their contribution, as well as John Milsom (Queen Mary College).

This work would not have been possible without the kindness and cooperation of the local people in the Mangani area, and the labourers who worked for me. These people put up very well with the activities of the mad lady geologist.

Chapter 1 Introduction

From 1975 to 1980 the British Institute of Geological Sciences (IGS) and the Indonesian Departement of Mineral Resources (DMR) collaborated on the North Sumatra project (Page et al., 1978). This involved regional geological mapping and reconnaisance stream sediment geochemistry of Sumatra north of the equator. As a result of this work a number of areas of possible economic importance were selected for further investigation. Mangani was one such area.

Four veins at Mangani had been mined for gold and silver during the Dutch colonial period, but the mine was abandoned during World War II, and the area has reverted to jungle.

1.1.1 Research objectives.

Investigation of the Mangani area was considered to be important for the following reasons:-

1/ Geological investigation.

Knowledge of the geology of large areas of Sumatra is still limited to the regional picture, and any detailed study in such areas can be of value in defining the boundaries of geological units more precisely

2/ Location of the mineralisation.

The main aim of the study at Mangani was the investigation of the mineralisation in the area. The location of a number of veins was known from published accounts (e.g. De Haan et al., 1933), but veins which were not economic at that time had never been investigated, and it seemed likely that not all the mineralisation had been discovered. Geological mapping, stream and soil geochemistry, and geophysics have been used to investigate the precise location of mineralisation.

3/ Investigation of the best methods for locating such mineralisation.

Mangani and a number of other similar deposits once produced a significant amount of gold. Identification of an efficient method of prospecting for such deposits in the tropical mountainous terrain of Sumatra, would enable Indonesia, and similar SE Asian countries, to become significant gold producers again.

4/ Types of mineralisation present.

Published accounts of mineralisation in the Mangani Vein (e.g. De Haan et al., 1933, Kieft and Oen, 1974), suggested that a very complex composite deposit was present. Very little was known about the uneconomic veins. An examination of the mineralisation types present would enable elucidation of the history of deposition of such deposits.

5/ Mode of formation of the mineralisation

Detailed investigation of the mineralisation was aimed at discovering the way in which the deposits at Mangani formed, and the role of the structure and geology of the area in determining the location of the mineralisation.

6/ Comparison of Mangani with other mines, and investigation of the mode of formation of all these deposits.

A final part of this study was the comparison of Mangani with similar deposits in Sumatra, and investigation of the possibility that these deposits formed as a result of a common cause. This would allow particular geological environments to be proposed where exploration for such mineral deposits should be carried out.

7/ Investigation of the relationship between plate tectonics and the mineralisation in Sumatra.

The mineralisation at Mangani is hosted in volcanics, near a part of the Sumatran Fault System (SFS). Both the volcanism and the faulting are probably related to plate tectonic processes. If a relationship between the mineralisation and the plate tectonic setting can be demonstrated, other areas of the world with similar mineralisation potential may be identified.

1.1.2 Location

Sumatra is an elongate island, aligned NW-SE, with a length of 1700 km, and a width of 200-350 km. Mangani is situated half way along the island, exactly on the equator, a few kilometers west of the water divide between east and west Sumatra (Fig 1). The area was reached by travelling by road to Puar Datar, then on foot along the old mine road. Since completion of the survey the road has been rebuilt by C.S.R Ltd.

1.1.3 Geographical details.

The Mangani district is mountainous with deeply incised valleys. One waterfall is reputed to be 120m high, although this cannot be reached unless the water level in the gorge below is unusually low. The lowest point in the area is about 650m and the highest 1200m.

Tropical rainforest covers the whole region, with the nearest inhabited districts being 15 km to the south (Puar Datar), and 12 km to the west (Bonjol).

Rainfall is high, averaging 5233mm over the years 1920 to 1929, with the wettest months being October-November and March-April (De Haan et al., 1933, Rock et al., 1980).

Due to the altitude the temperature can be low at night (15^{o}C), while the daytime temperature often reaches 25^{o}C.

The largest scale topographic maps covering the area are sheets numbers 77 and 83 on a 1:40,000 scale (Fig. 2). These maps were first compiled at the end of the last century (1894-1898), and are highly inaccurate, even though they were revised in 1926.

A 1:5,000 map of the southern part of Mangani was produced by the geophysical section of D.M.R in 1978 (Harsono et al., 1978), and is reduced to 1:10,000 in

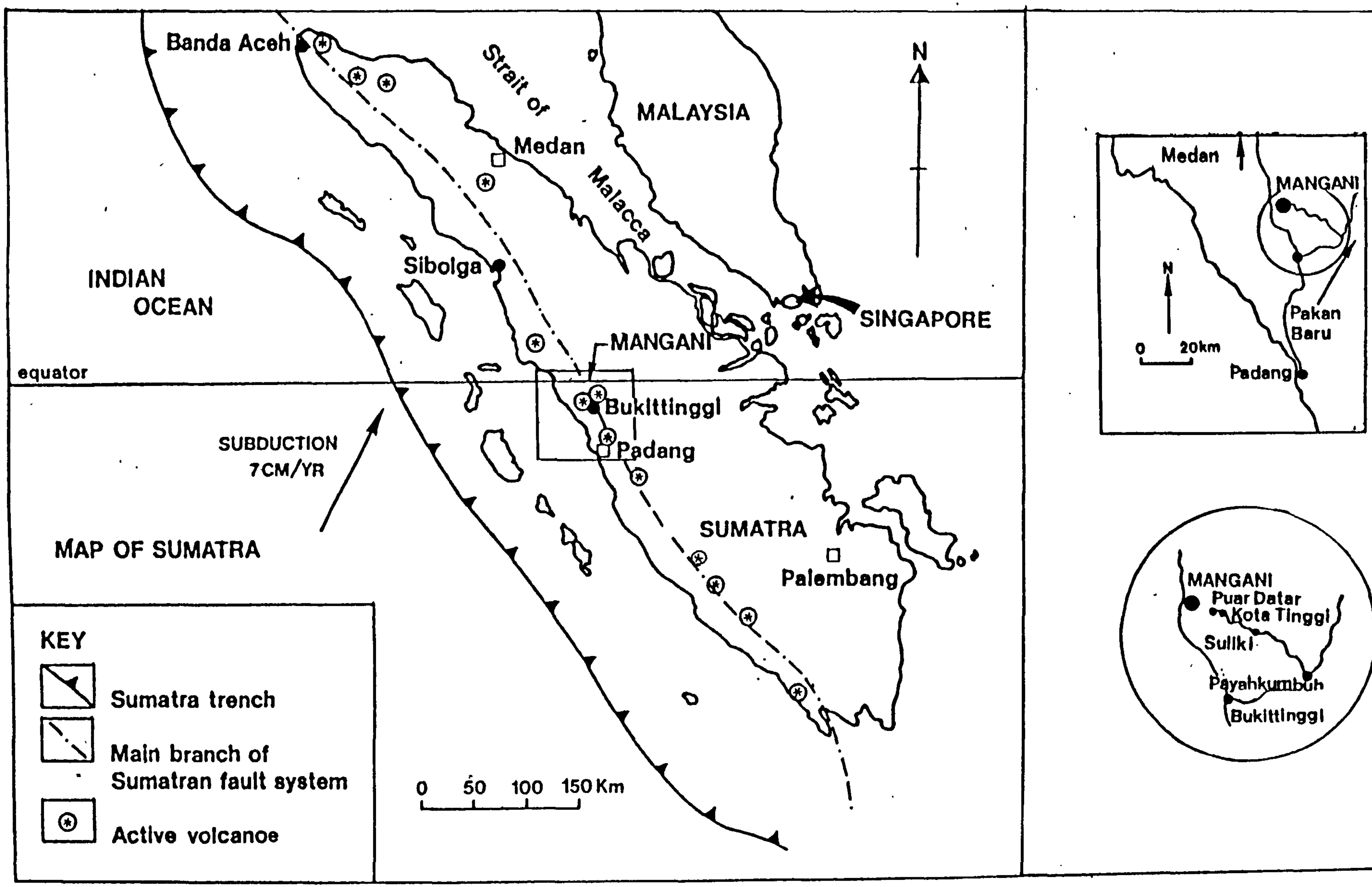


Figure 1
Teconic setting of Sumatra, and location of the Mangani area.

Figure 3. Part of the Bukit Bulat area in the northern part of Mangani, as well as the Rambutan-Silver Vein area were surveyed on a 1:2,000 scale as part of the present geophysical programme. (Fig. 4, Enclosure 1). Some of the stream courses in mineralised areas were surveyed on a 1:500 scale using a tape and compass. A number of maps of the Mangani drainage system are reproduced in De Haan et al. (1933) and Wing-Easton (1926).

I have compiled a 1:10,000 map of the entire Mangani area based on air photographs combined with field observations and the information from all the other available topographic maps. This map is shown in many figures, including Figure 5, which shows the locations of the veins, as well as the survey grids used to investigate two of the mineralised areas. The 1:10,000 map of the stream courses produced is reduced and used as a base for many of the other figures, including the geochemical maps in Chapter 3.

Aerial photographs covering the area are on a nominal scale of 1:100,000, and were flown by the Royal Australian Air Force in 1974. Most of the area is cloud free. Reasonably cloud free Landsat coverage was obtained in 1973 (Plate 1).

1.2 Regional tectonic setting.

Sumatra forms part of the Sundaland continental plate which covers most of S.E. Asia. Ocean crust of the Indian-Australian plate is being obliquely subducted NNE wards (023°) under the western margin of the Sundaland plate, forming a volcanic arc (Fig. 1)(Hamilton 1979). Uplift of the area adjacent to the Sumatra Fault System and volcanism during Tertiary and Recent times has resulted in the formation of the Barisan mountains trending parallel to the west coast of Sumatra. Oblique subduction has caused dextral faulting parallel to the plate margin, the Sumatran Fault System (SFS) forming a median valley through the Barisan mountains (Fig 6)(Fitch 1972). In the north the S.F.S links with a series of transform faults associated with the Andaman Sea Spreading Complex (Curray et al., 1979).

Some of the volcanoes active at the present time can

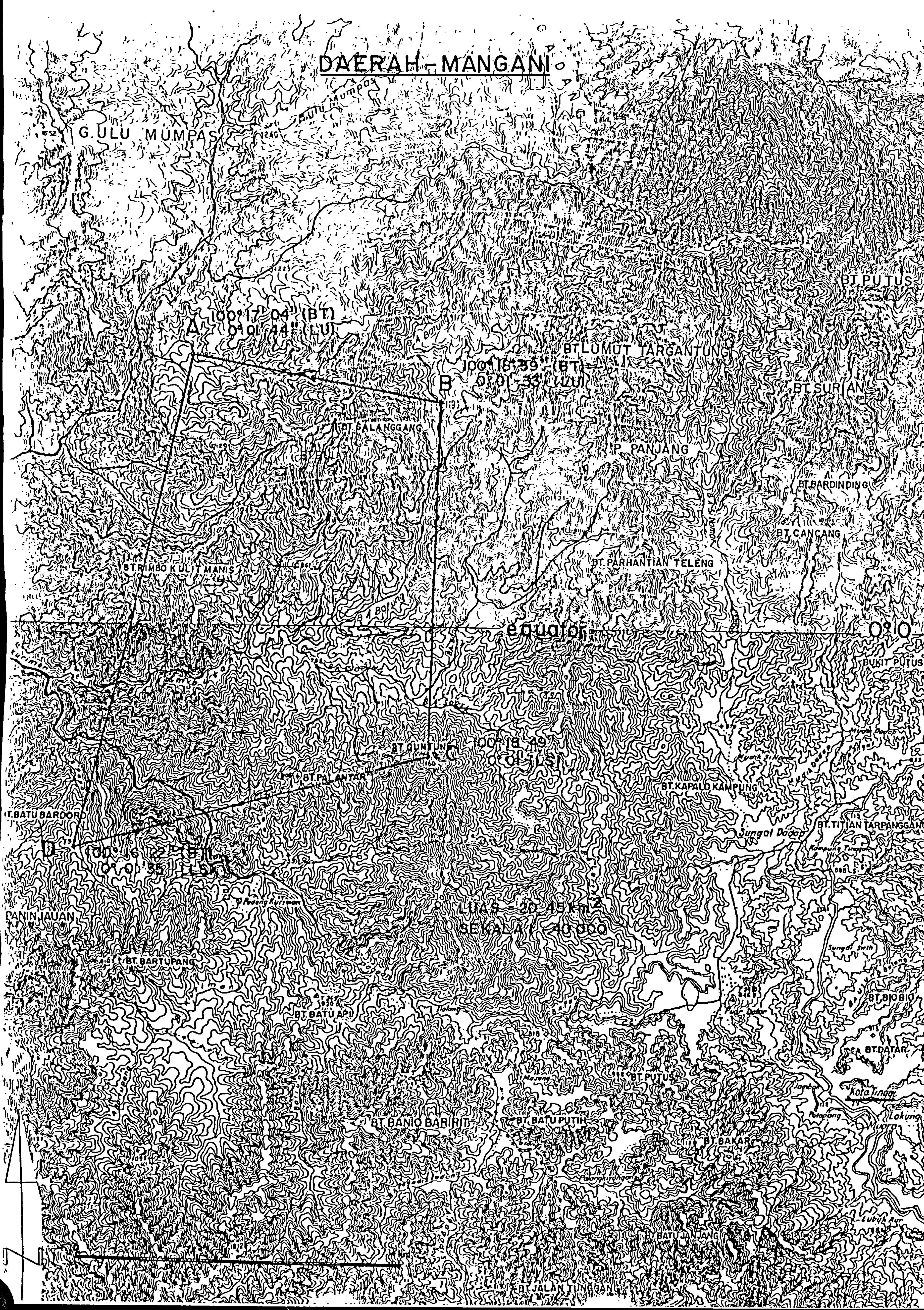


Figure 2 Published topographic map of the Mangani area.

Figure 3 Topographic map of the southern part of Mangani. (Harsono et al. 1978)

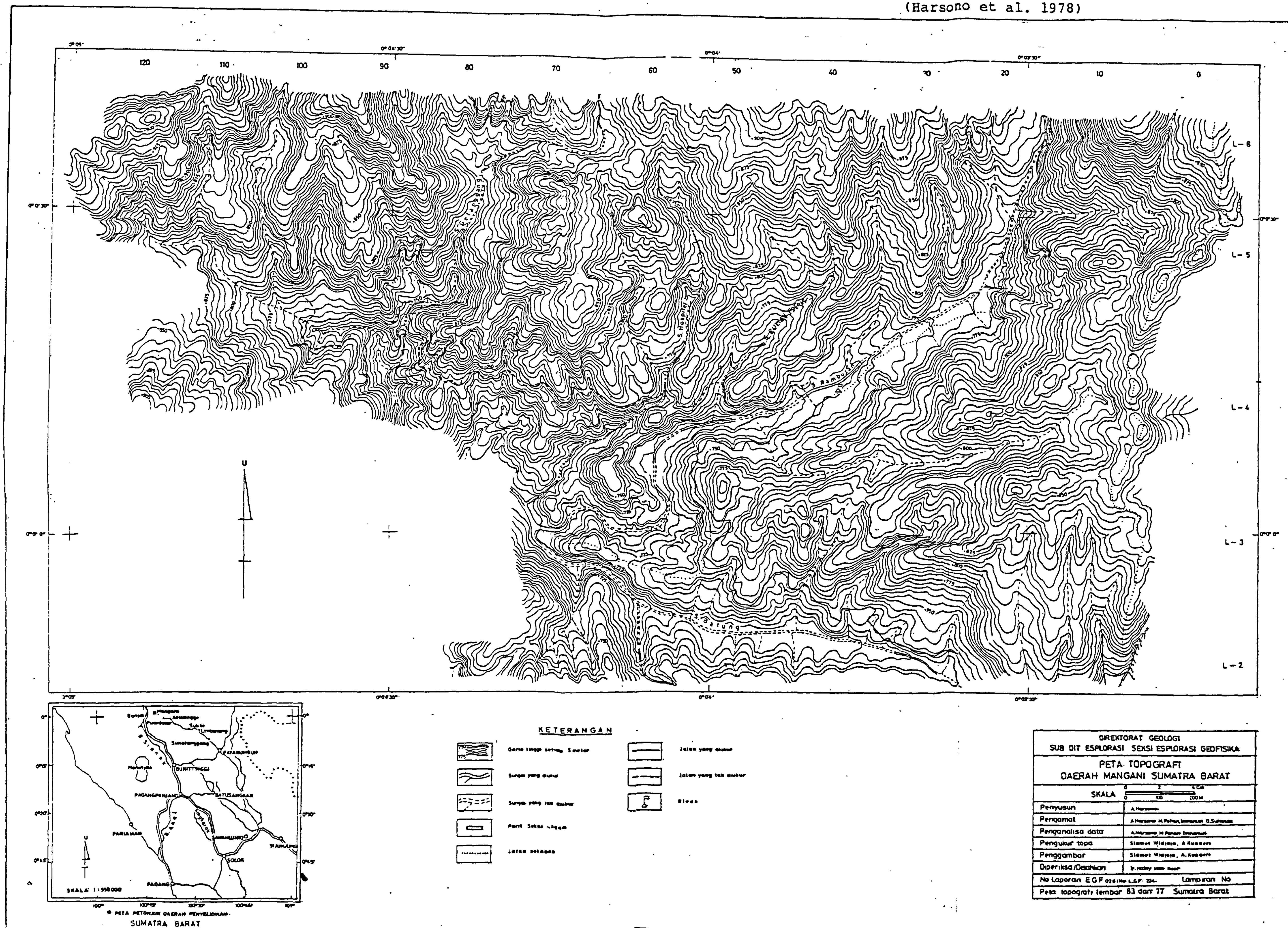
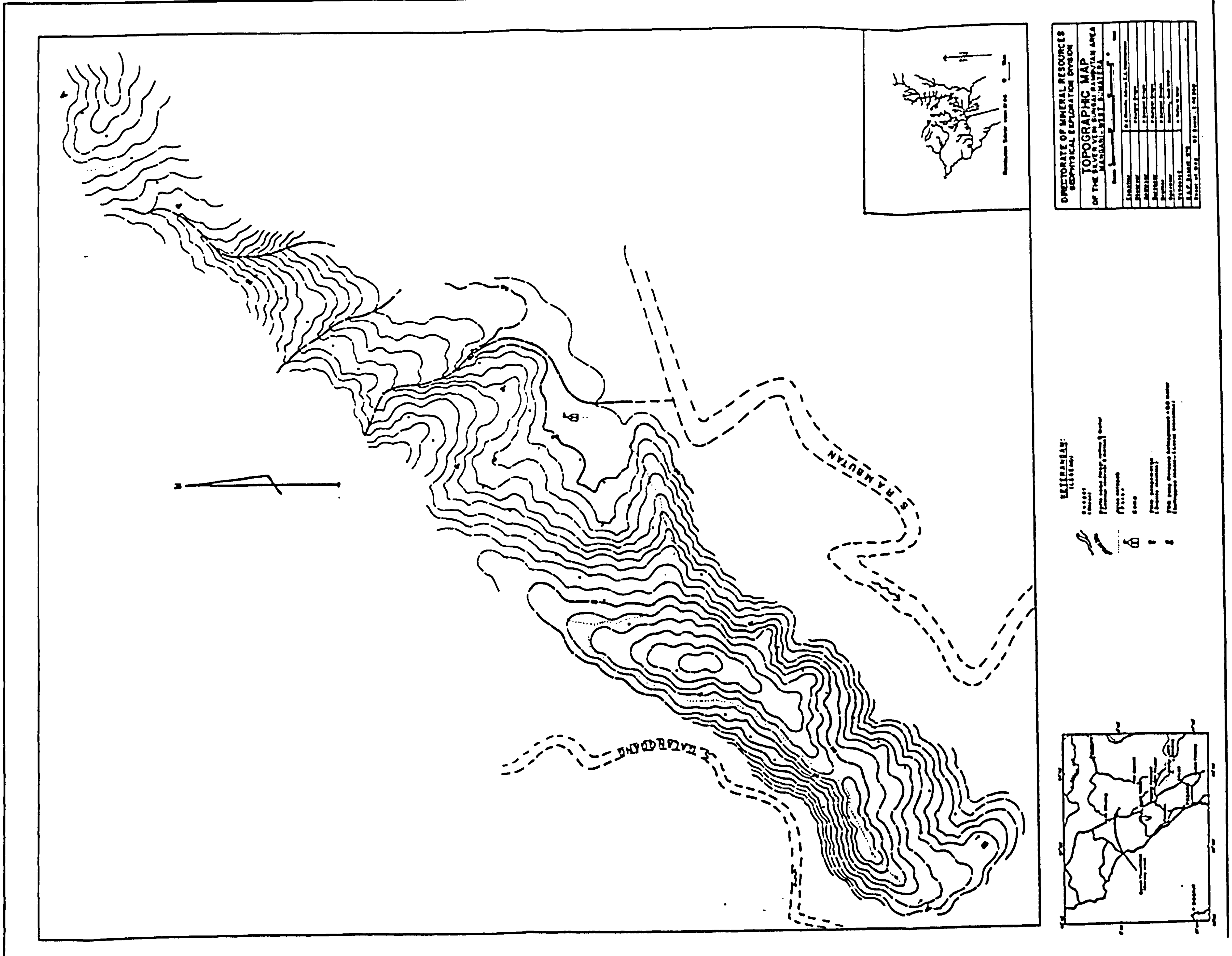


Figure 4 Topographic map of the Rambutan-Silver Vein area. prepared as part of this project



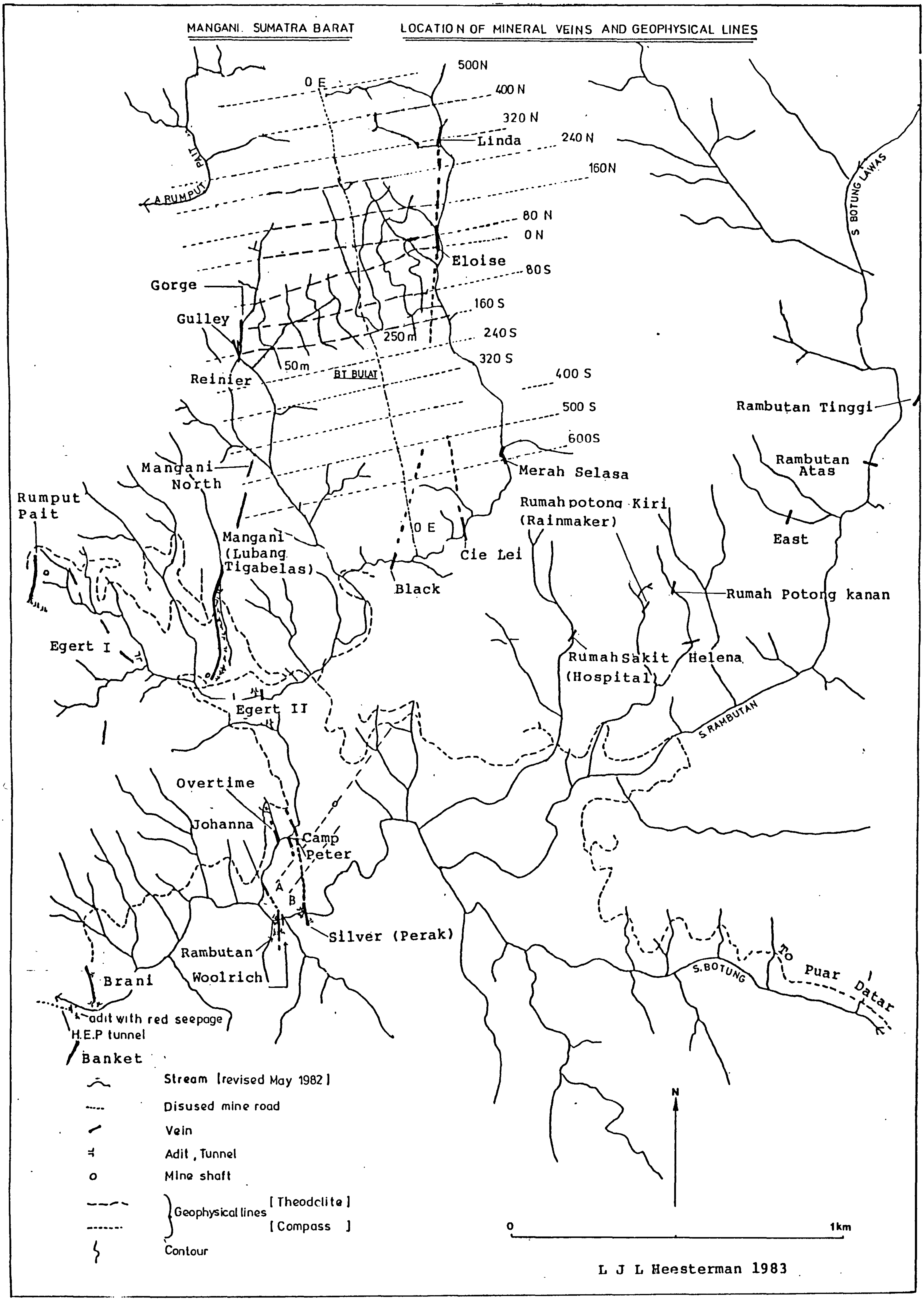


Figure 5 Location of mineral veins, and geophysical lines.

be seen in the Landsat image in Plate 1, as well as some of the different faults related to the SFS. Mangani lies on an eastern (inactive) splay of the SFS in the Barisan mountains.

The plate tectonic setting, including the relationship between the Malaysian mainland and Sumatra has been described by Hamilton (1977), and Cameron (1981). A tectonic map published by IGS/DMR in 1982 was used to produce Figure 7 , and shows some of the subdivisions proposed for Sumatra and Malaysia. If these divisions are valid, the mineralisation at Mangani lies above basement of the Mergui platelet.

1.3 Regional Geological History.

Sumatra contains a continental core of Paleozoic sediments and volcanics, as well as possibly even older crystalline schists and migmatitic gneisses (Page et al., 1978).

Following important metamorphic, tectonic and plutonic activity which affected the Mesozoic rocks, the Tertiary sediments and volcanics were deposited on an irregularly eroded land surface. Deposition occurred in several distinct basins (Fig. 8), the Central Sumatra Basin being the largest. These basins were formed by subsidence in grabens along a north trending structural grain, and along a younger NW trend. In the Oligocene marine transgression started with deposition of nonmarine coarse sandstone and conglomerate in depressions in pre-existing topography. Subsidence continued until the Middle Miocene with formation of more marine deposits. The western part of basin appears to have been deeper than the east, with a maximum thickness of sediments of about 5000m. Near the end of the Middle Miocene subsidence slowed, and thick marine shales were deposited. At local highs, and the edges of the basins, shallow water limestone, carbonate and glauconitic sandstone were formed (Mertosono and Nayoan, 1974).

At the end of the middle Miocene, uplift of the Barisan mountains, and regression in the basins coincided

Figure 6 Drainage pattern, Sumatra, Indonesia.

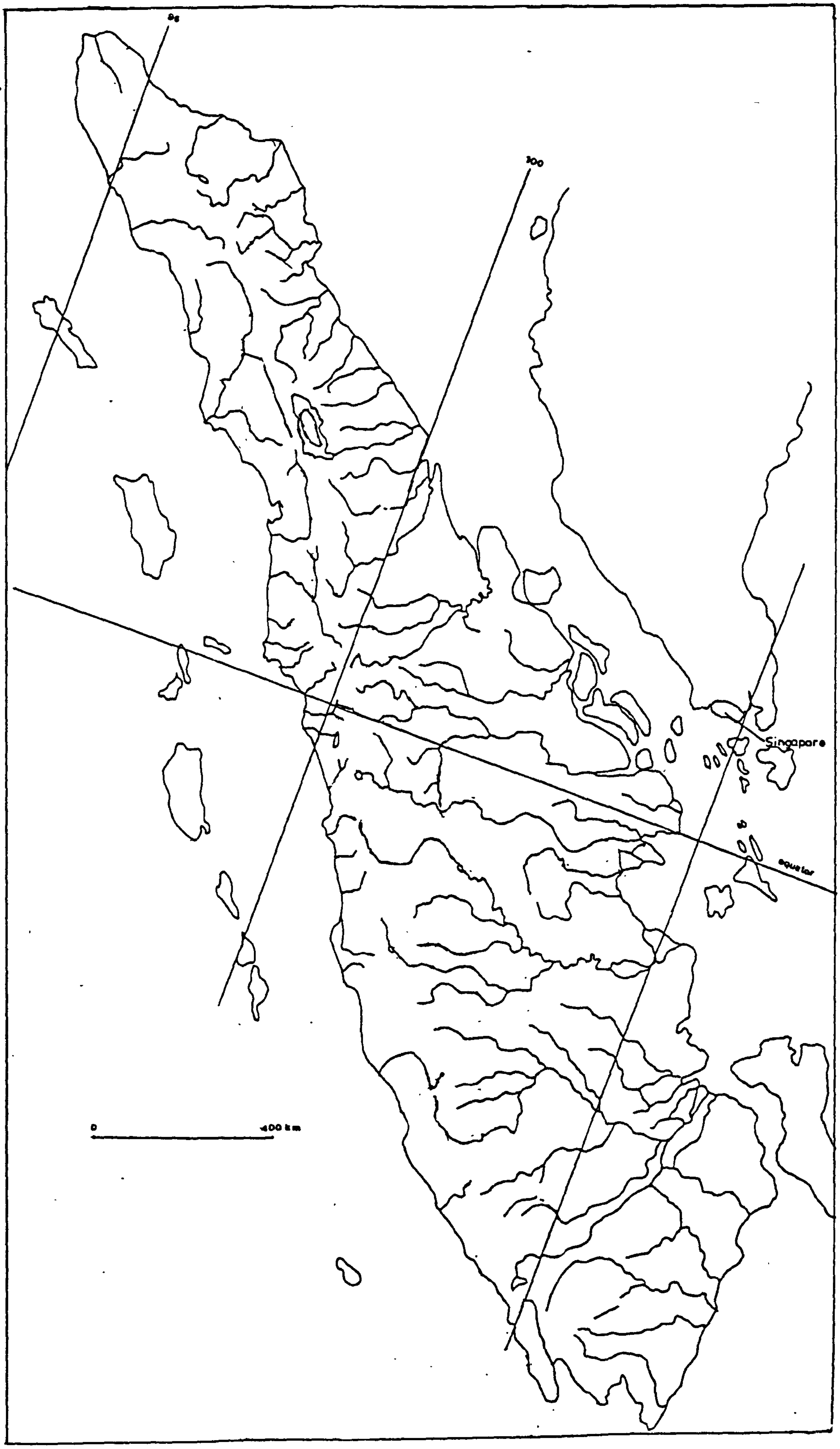
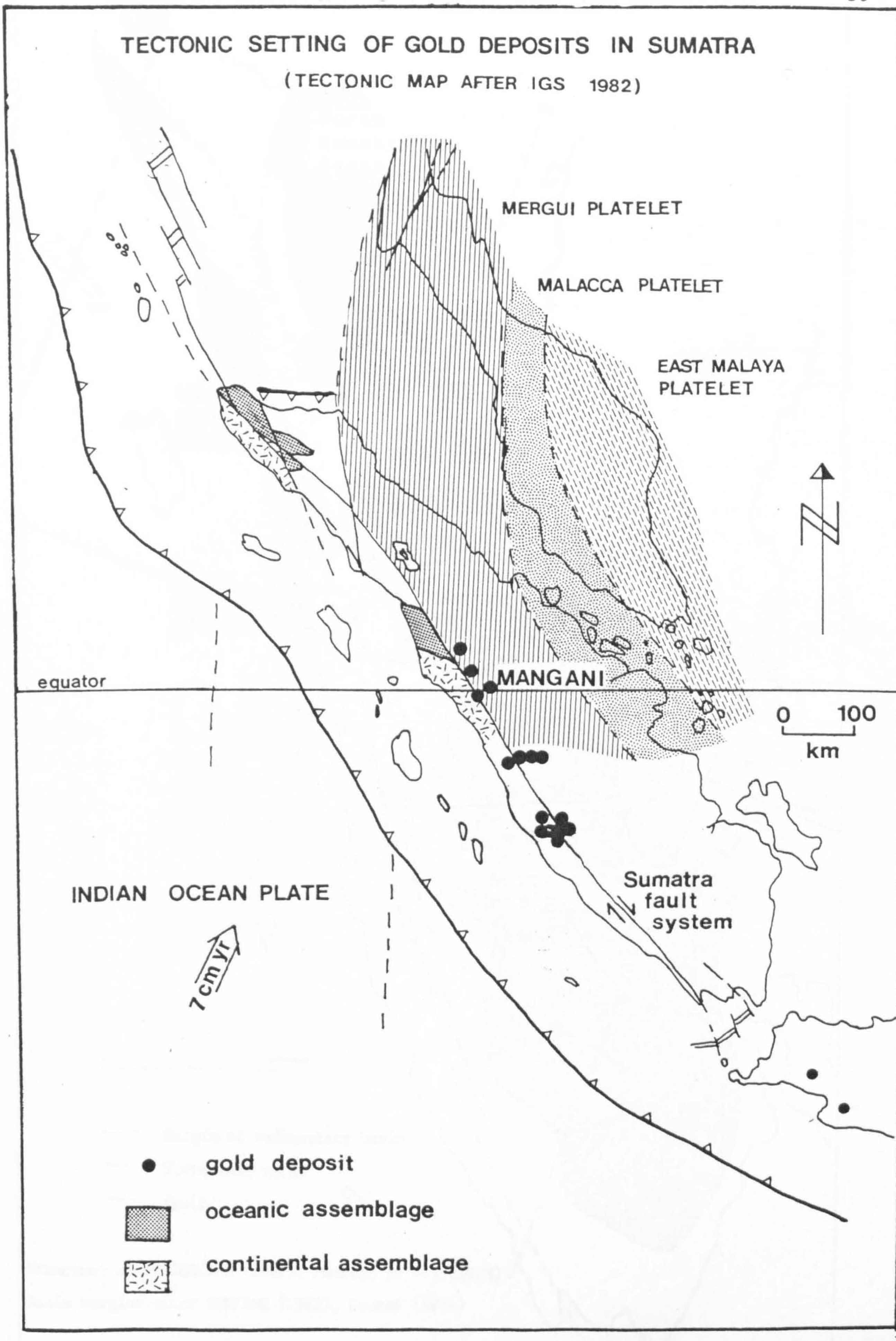
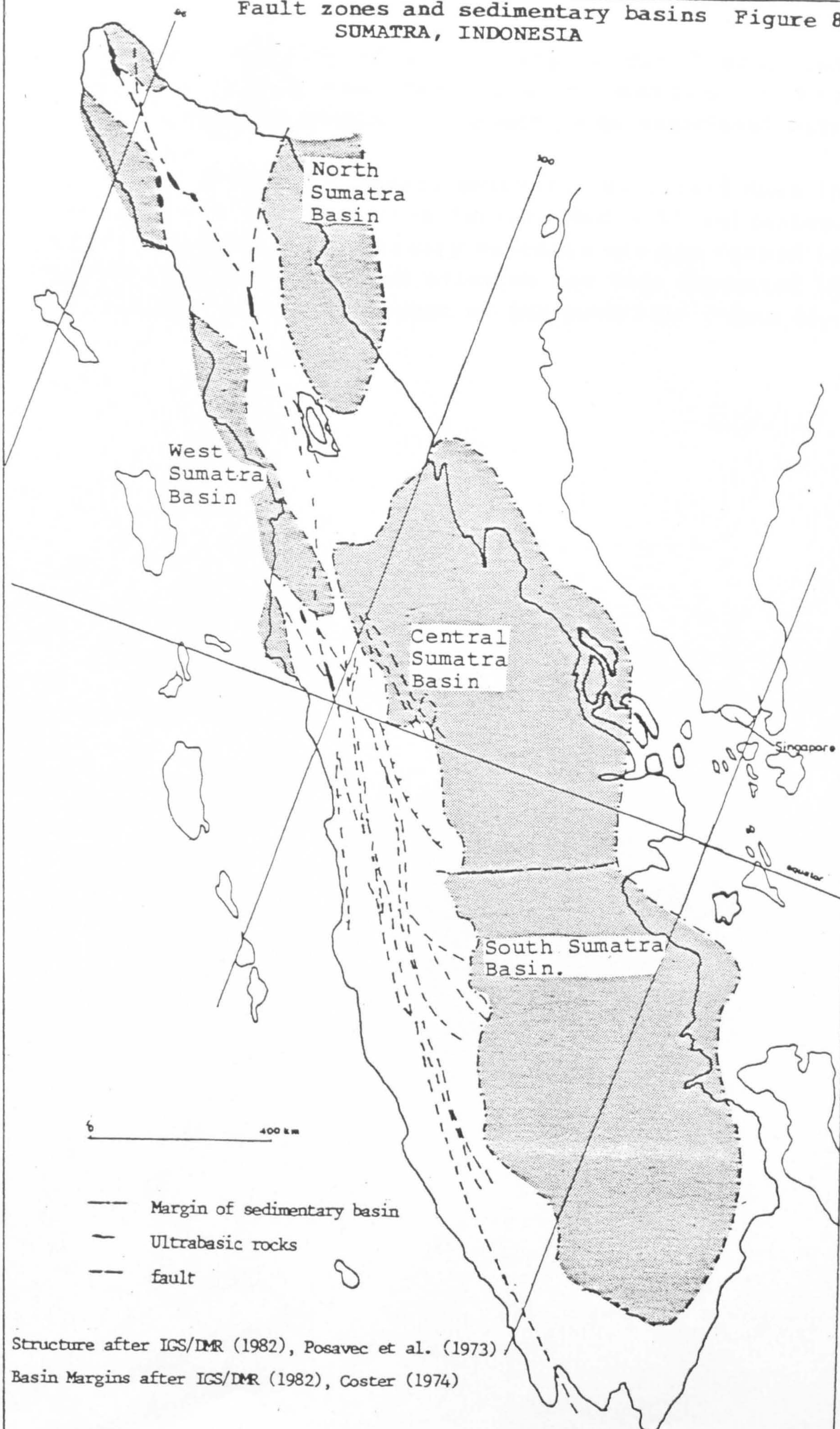


Figure 7 Tectonic interpretation of Sumatra.



Fault zones and sedimentary basins Figure 8
SUMATRA, INDONESIA



Structure after IGS/DMR (1982), Posavec et al. (1973)

Basin Margins after IGS/DMR (1982), Coster (1974) with the formation of a Tertiary volcanic arc, and movement along the SFS. The formation of the mineralisation at Mangani is thought to be associated with this phase.

Upper Miocene-Pliocene sediments were laid down in intermontane basins, often interbedded with volcanics. Since that time, a Quaternary volcanic arc has formed in the Barisan mountains, and alluvium has been deposited in the lowland areas to the east of the mountains (Plate 1).

Plate 1 Landsat image showing the relationship of the Mangani graben to the Sumatra Fault System.

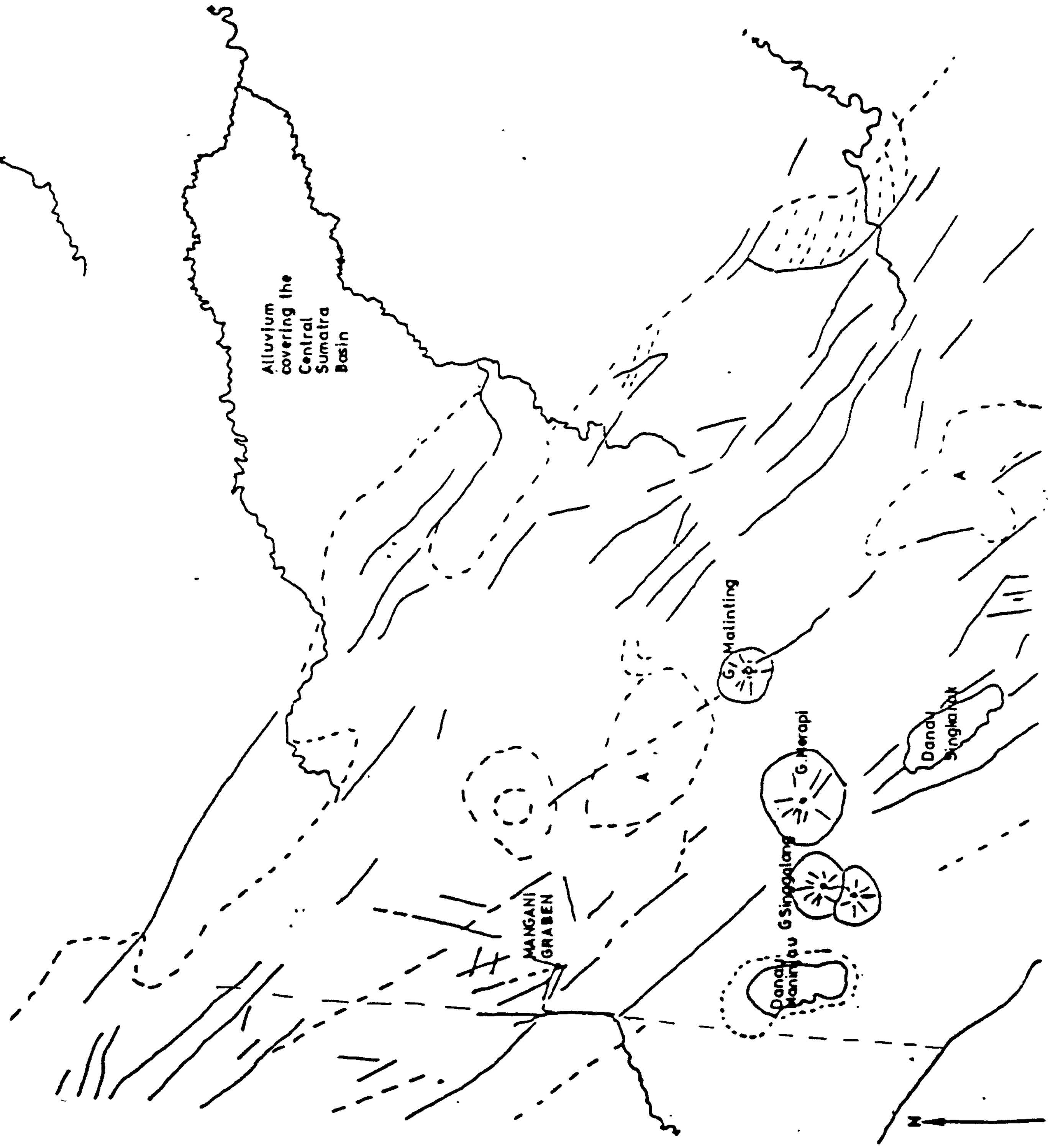



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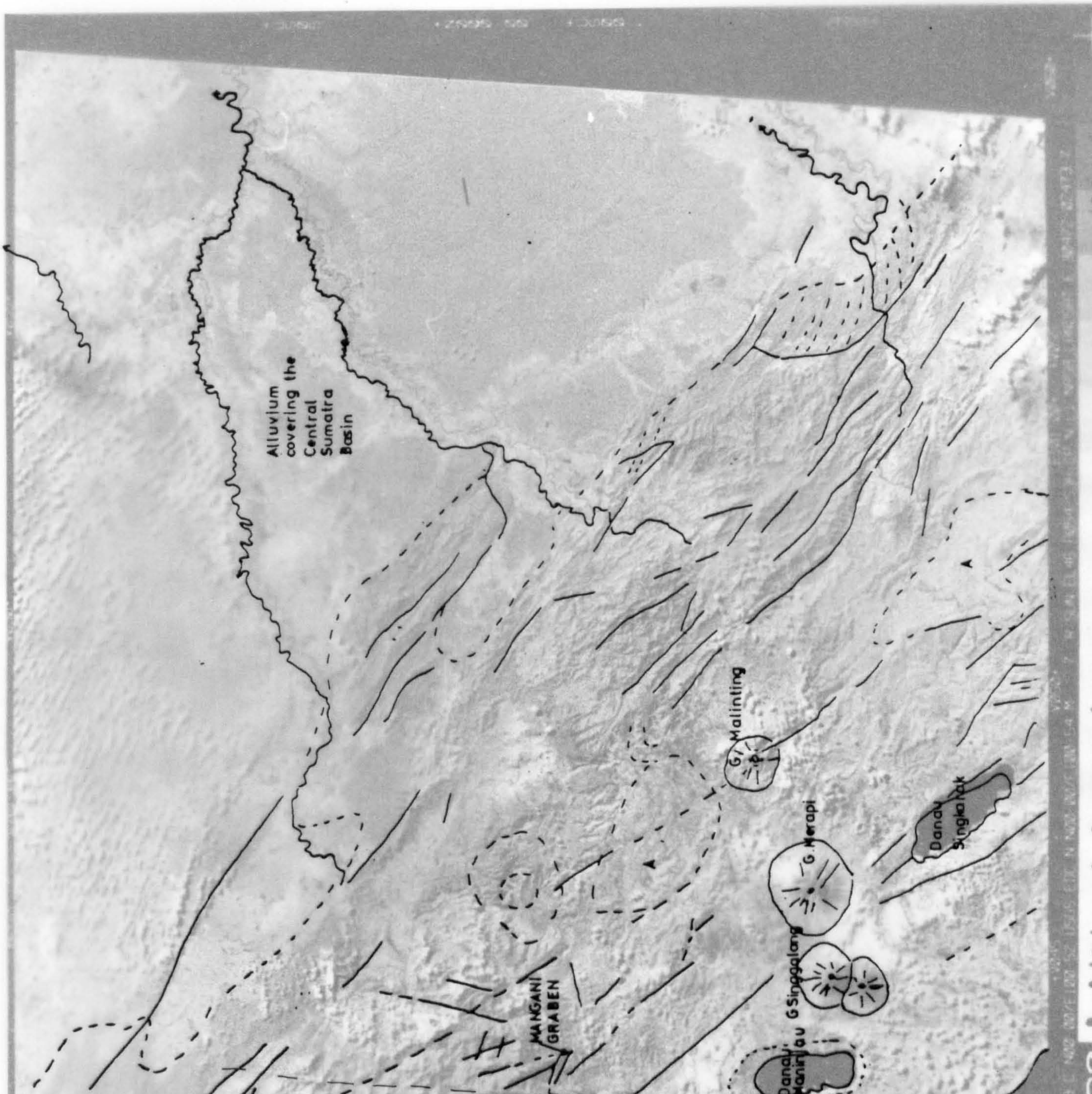
Plate 1 Landsat image showing the relationship of the Mangani graben to the Sumatra Fault System.



Chapter 2

The geology and structure of the Mangani area.

2.1.1 Introduction.

In most areas of West Sumatra the basement consists of the Kuantan Formation, part of the pre-Tertiary Tapanuli Group, considered to be early Carboniferous to middle Permian in age. Lithologies are slates, meta-quartzites and meta-limestones. Further north the Kuantan Formation has also been called the Kluet Formation. The pre-Tertiary does not outcrop in the area mapped at Mangani, but is reported to occur in valleys further to the west (De Haan et al., 1933, Rock et al., 1980)

The pre-Tertiary basement is overlain by Tertiary sediments in the Central Sumatra Basin, and the West Sumatra Basin, which is partially located offshore (Fig. 8). Some sediments are also thought to have been deposited in intermontane basins and grabens.

Mangani lies in the western part of the Central Sumatra Basin, where basal conglomerates and clean quartzites (Sihapas Formation) were deposited during the early Miocene marine transgression.

These pass up conformably into the Telisa Formation, consisting of mudstones and limestones. Locally interbedded tuffs suggest that volcanism started at this time.

In the Mangani area the Brani Conglomerate has been interpreted as the lateral equivalent of the Sihapas Formation (e.g. Rock et al., 1980), but may be an older graben fill, alluvial fan deposit. The Brani conglomerate consists of quartzite and phyllitic clasts derived from the pre-Tertiary basement, with the frequent occurrence of a red haematitic muddy matrix suggesting a continental environment.

After deposition of the Telisa Formation the Barisan area became emergent, and volcanism commenced in earnest, and most younger rocks consist of tuffs and lavas. Later sediments were deposited in intermontane basins. Information about the geology of West Sumatra is derived from Van Bemmelen (1970), Rock et al. (1980), Kamili et al. (1973), and Cameron et al. (1981).

2.1.2 Summary of the geology at Mangani.

Field mapping combined with aerial photograph and Landsat interpretation (Plates 1,2) showed that the Mangani area includes an area of Brani Conglomerate in the south, and Sihapas and Telisa Formation sediments in the north, separated by a fault-bounded graben.

Infilling the graben and overlapping onto adjacent horsts are a series of tuffs of very varied composition. These features are shown on the generalised geological map of the Bonjol/Mangani district and the surrounding region (Fig. 9), and in the simplified geological map and cross section of the Mangani area (Figures 10,11).

The Sirabungan and Guntung volcanics are the youngest of these tuffs, and form a blanket across the horst and graben structures, a feature which can be seen most clearly in Figure 9.

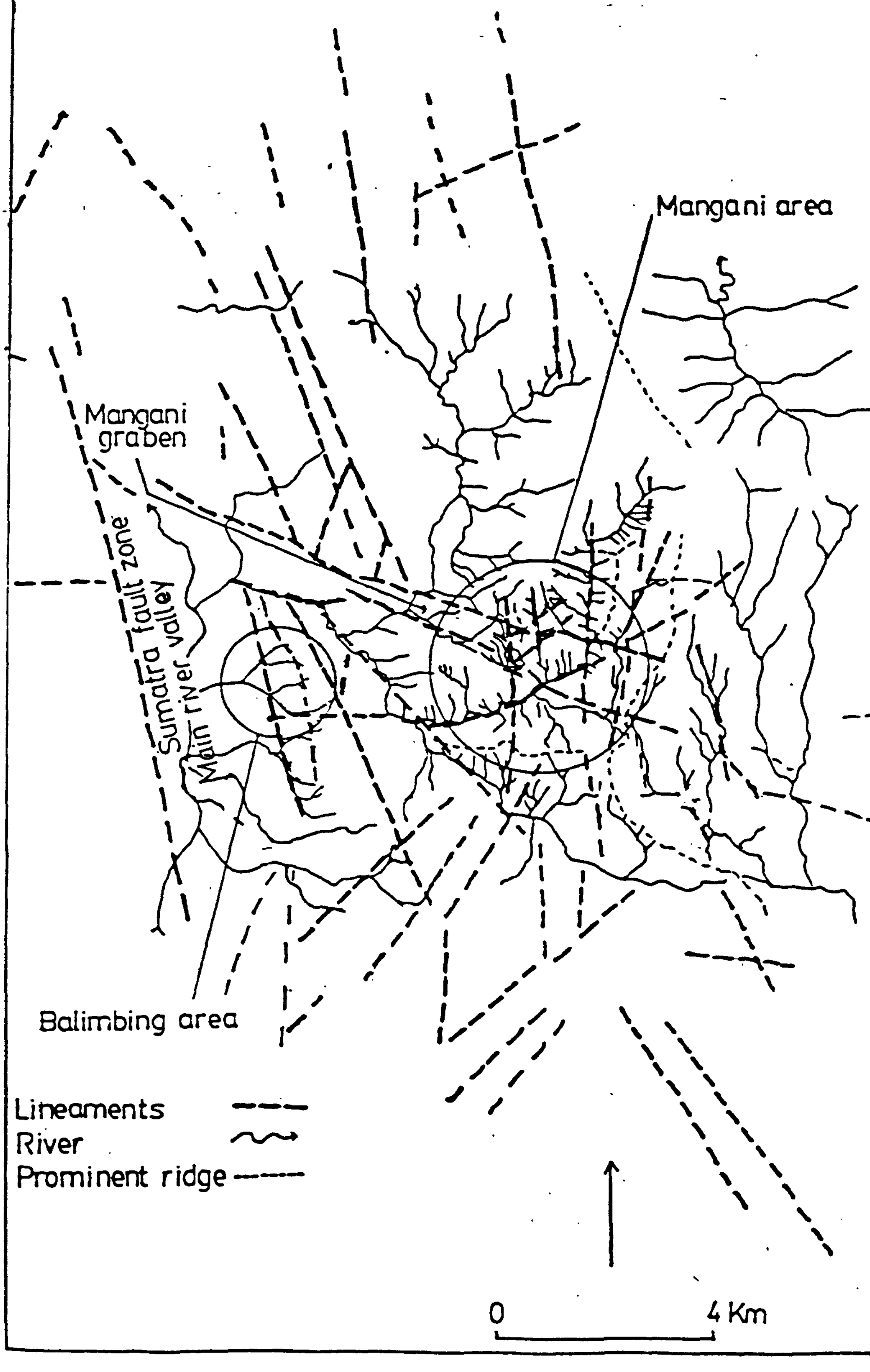
Pre-Tertiary slates are described by De Haan et al. (1933) as occurring in the base of deep valleys to the west of Mangani, so presumably underlie the succession described above. Pre-Tertiary rocks also outcrop to the NW of the Mangani area (Fig. 9), in the lower ground forming the main median valley of the S.F.S.

Scattered in the northern part of the Mangani Graben are a number of small areas of quartz porphyry and granodiorite which may be part of a larger intrusion. The intrusion may be related genetically to the volcanics, and also to the mineralisation.

Over large areas the rocks have been hydrothermally altered and permeated with disseminated sulphides.

Scattered throughout Mangani are a number of gold-bearing quartz and mineral veins. As a result of the present study the number of known veins has been doubled (now 32). Between 1912 and 1940, four of these veins (the Mangani, Rumput-Pait, Ramboetan and Perak veins) were mined by M.M. Aequator and Marsman for gold and silver.

Plate 2 Air photograph interpretation, showing the relationship between the Mangani Graben, and the Sumatra Fault System.



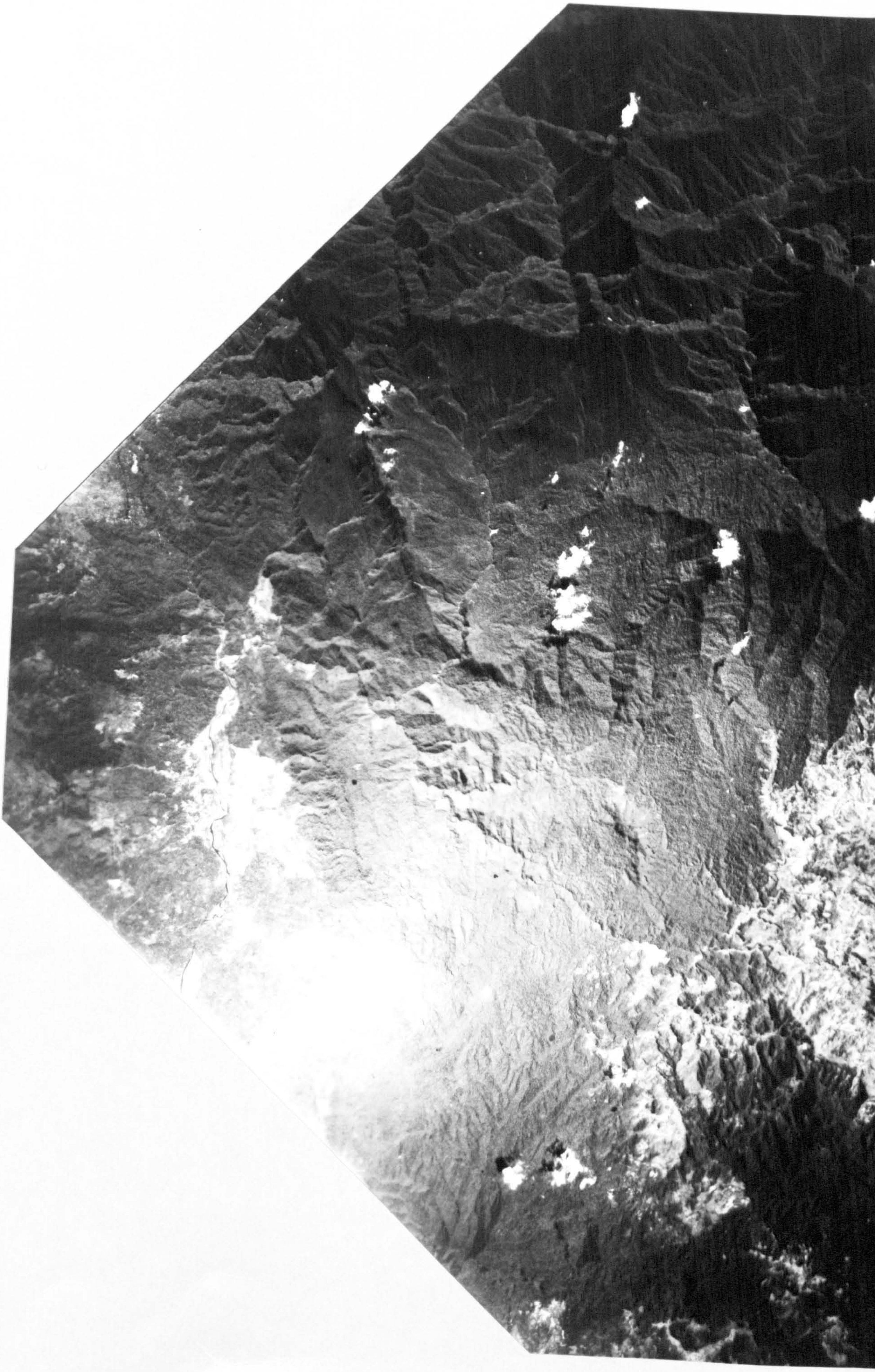


Plate 2 Air photograph interpretation, showing the relationship between the Mangani Graben, and the Sumatra Fault System.

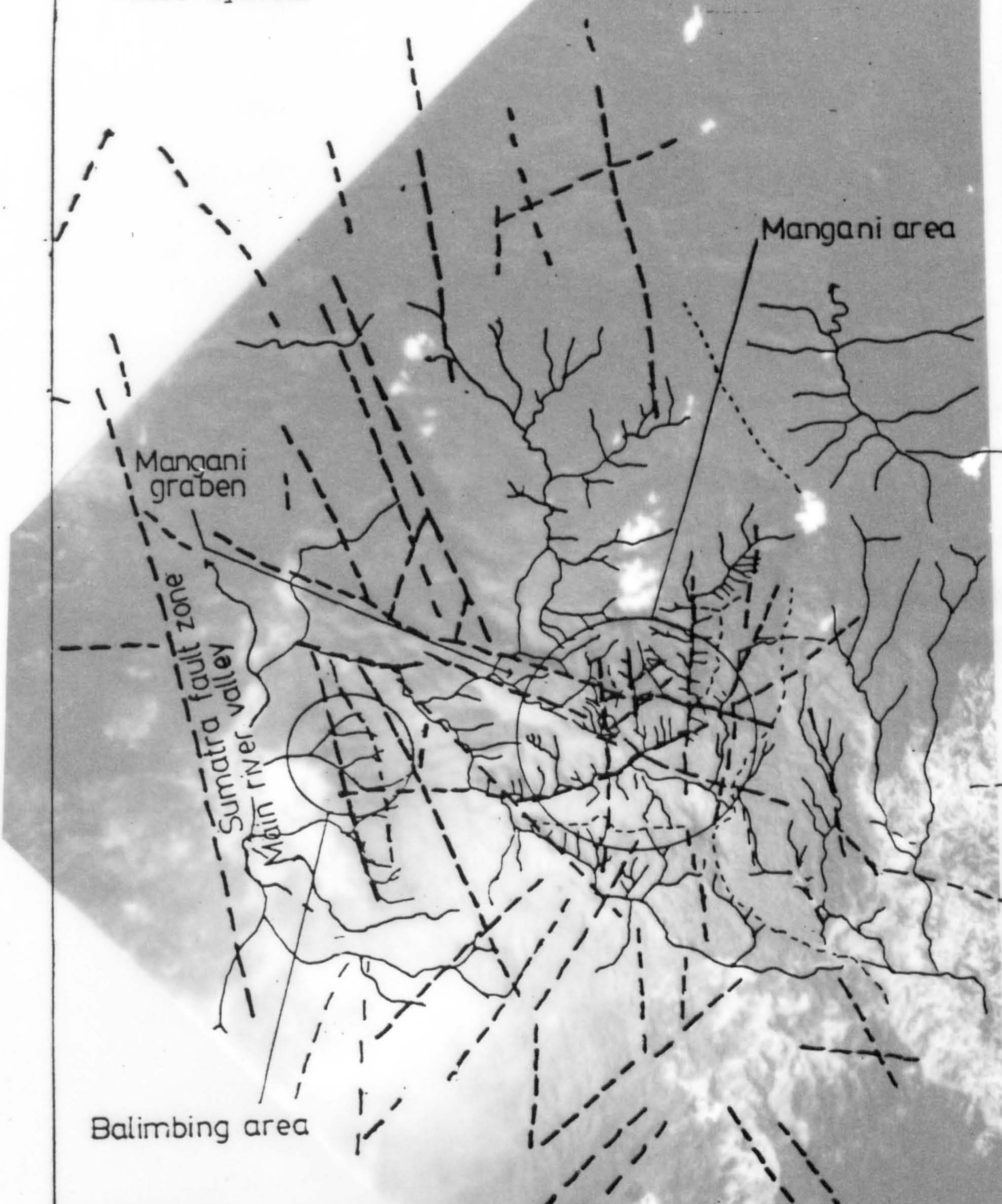
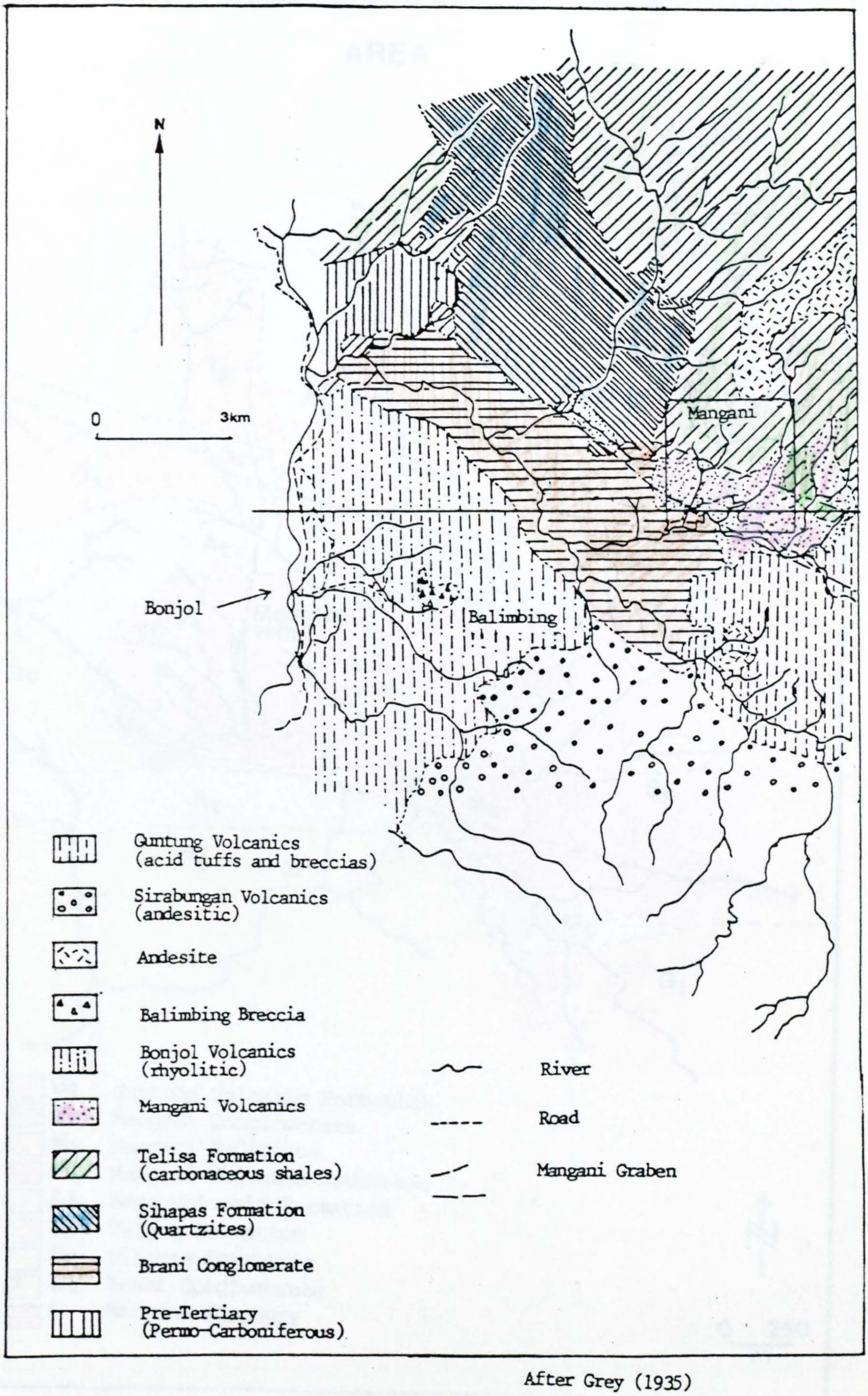
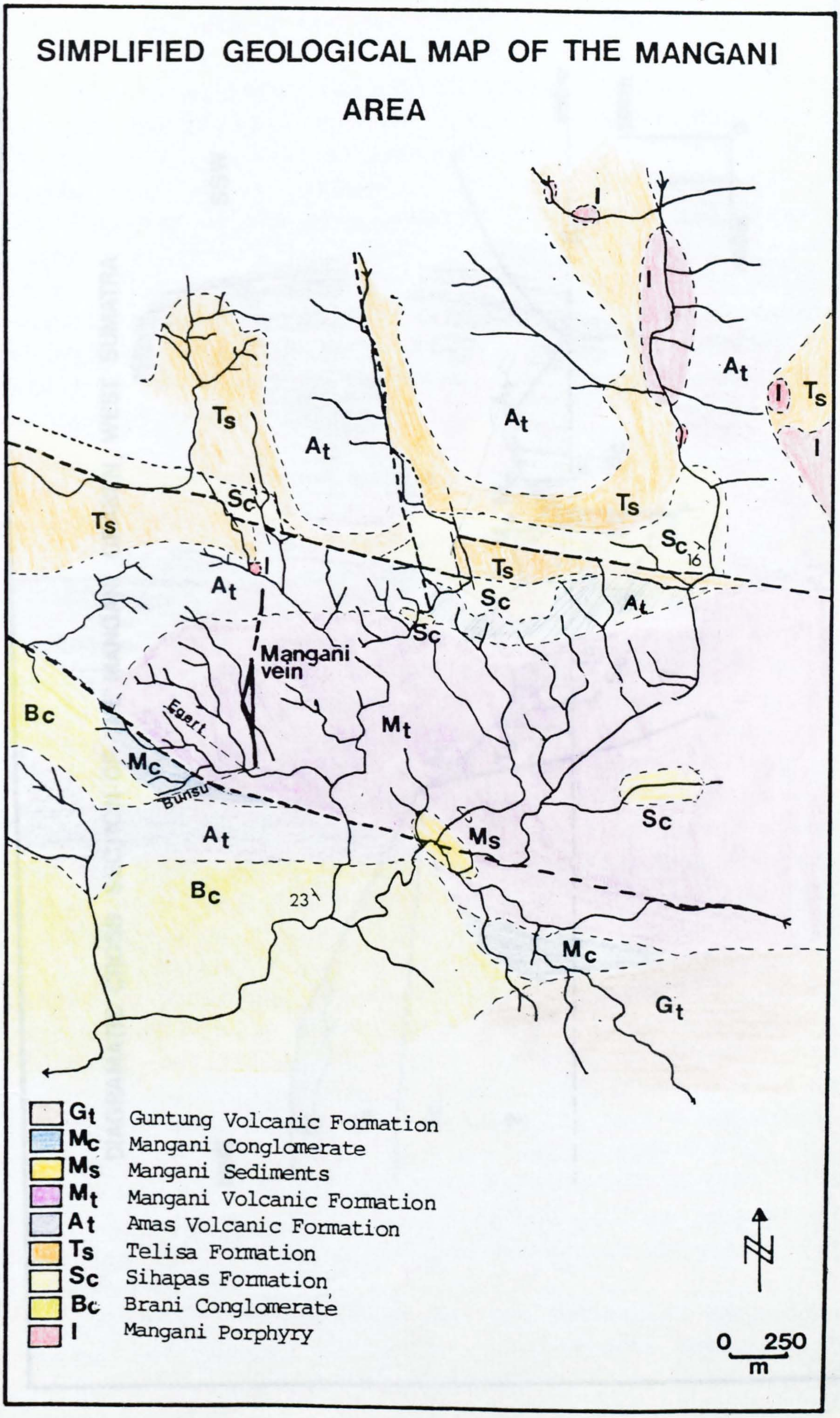


Figure 9 Geological formations in the Bonjol-Mangani district.



After Grey (1935)

Figure 10


SIMPLIFIED GEOLOGICAL MAP OF THE MANGANI AREA
I
At
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Mangani vein
Egert
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Gt
23
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Gt Guntung Volcanic Formation
Mc Mangani Conglomerate
Ms Mangani Sediments
Mt Mangani Volcanic Formation
At Amas Volcanic Formation
Ts Telisa Formation
Sc Sihapas Formation
Bc Brani Conglomerate
I Mangani Porphyry
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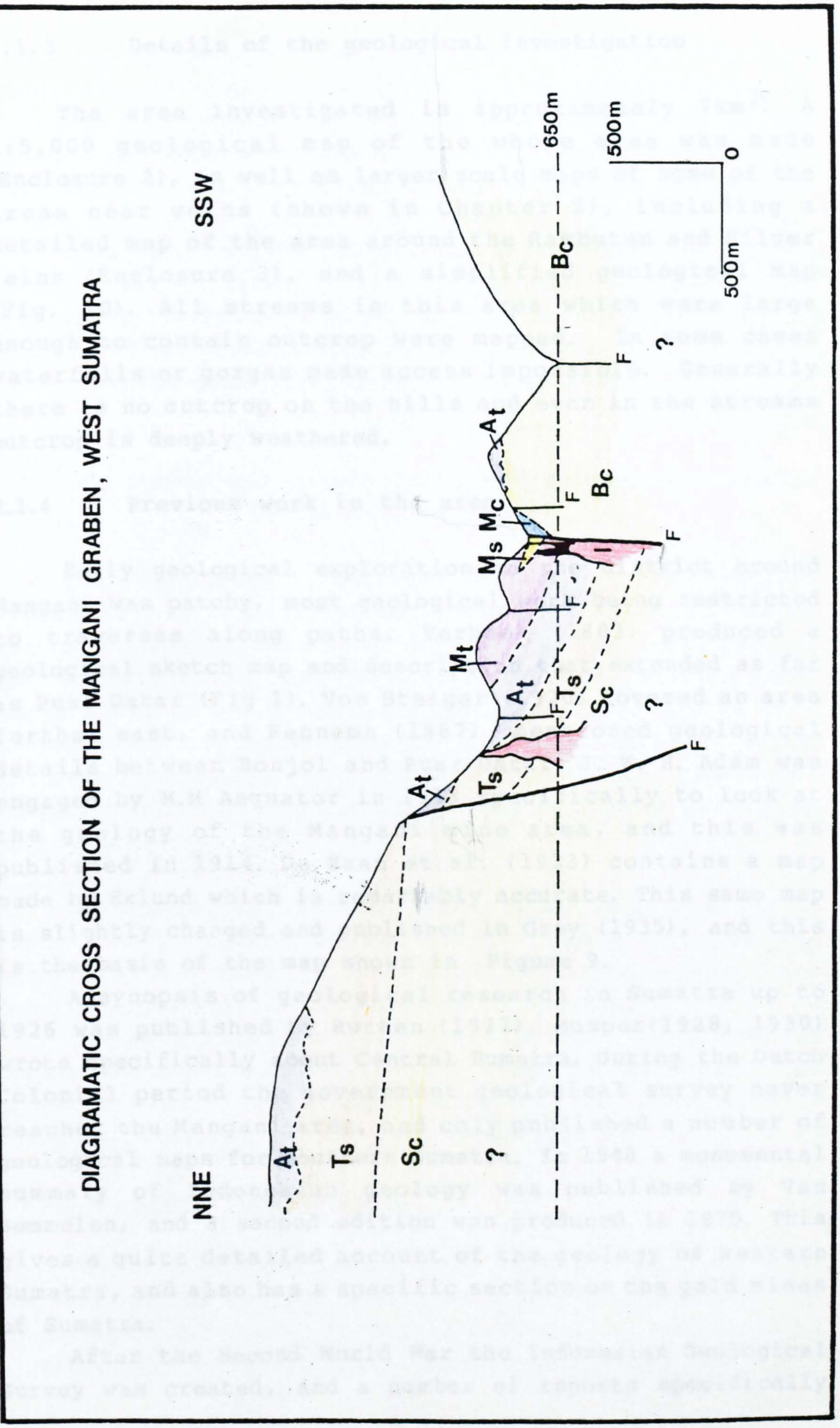
Figure 11 Diagrammatic cross section of the Mangani graben.



2.1.3 Details of the geological investigation

The area investigated is approximately $7km^2$. A 1:5,000 geological map of the whole area was made (Enclosure 2), as well as larger scale maps of some of the areas near veins (shown in Chapter 5), including a detailed map of the area around the Rambutan and Silver Veins (Enclosure 3), and a simplified geological map (Fig. 10). All streams in this area which were large enough to contain outcrop were mapped. In some cases waterfalls or gorges made access impossible. Generally there is no outcrop on the hills and even in the streams outcrop is deeply weathered.

2.1.4 Previous work in the area.

Early geological exploration in the district around Mangani was patchy, most geological work being restricted to traverses along paths. Verbeek (1883) produced a geological sketch map and description that extended as far as Puar Datar (Fig 1). Von Steiger (1920) covered an area further east, and Fennema (1887) mentioned geological details between Bonjol and Puar Datar. J. W. H. Adam was engaged by M.M Aequator in 1913 specifically to look at the geology of the Mangani mine area, and this was published in 1914. De Haan et al. (1933) contains a map made by Eklund which is remarkably accurate. This same map is slightly changed and published in Grey (1935), and this is the basis of the map shown in Figure 9.

A synopsis of geological research in Sumatra up to 1926 was published by Rutten (1927). Musper(1928, 1930) wrote specifically about Central Sumatra. During the Dutch Colonial period the government geological survey never reached the Mangani area, and only published a number of geological maps for southern Sumatra. In 1948 a monumental summary of Indonesian geology was published by Van Bemmelen, and a second edition was produced in 1970. This gives a quite detailed account of the geology of western Sumatra, and also has a specific section on the gold mines of Sumatra.

After the Second World War the Indonesian Geological Survey was created, and a number of reports specifically about the Mangani area were produced. These are described under the section relating to the mineralisation. In addition the geological map for the area south of the equator (Solok Quadrangle) was published in conjunction with the American Geological Survey (Silitonga and Kastowo 1975).

From 1975 to 1980 the British Institute of Geological Sciences worked together with the Indonesian Survey, and produced 1:250,000 geological maps of Sumatra north of the equator. The Lubuk Sikaping sheet (Rock et al., 1980) covers the Mangani area north of the equator.

2.2 The lower and middle Tertiary sedimentary sequence in the Mangani area.

The lithologies encountered at Mangani are described approximately in order of age, though no absolute dates are available for these rocks. A few samples of sedimentary rocks contained foraminifera, which showed those rocks to be of Tertiary age, but could not be used to subdivide the rocks into the different Tertiary units. No pre-Tertiary rocks are exposed in the area investigated, but the Kuantan Formation occurs to the NW of the area (Fig. 9).

The nomenclature used in this account is similar to that used by Clarke et al. (1980). Table 1 shows the nomenclature used by a number of authors who have described the Tertiary succession in Sumatra.

The stratigraphic relationships between different rock units are diagrammatically shown in the simplified cross section of the Mangani area (Fig. 11), and also on the geological map of the area (Enclosure 2).

2.2.1 Brani Conglomerate.

The Brani Conglomerate only occurs to the south of the Mangani Graben, and occurs as a horst, separated from the Sihapas and Telisa Formation sediments to the north by a graben approximately one kilometre wide (Fig. 10)

In the Mangani area this unit consists of thickly bedded (1-3m) conglomerates showing channelling (Plate 3a), and occasional doubtful imbrication. Clasts generally have a diameter below 15 cm.

Field observation and thin section examination enabled identification of the following types of clasts:- Subrounded to rounded, subspherical to irregular grey siltstones and quartzites, phyllite, metamorphosed conglomerate containing phyllitic clasts. Occasional unaltered and unmineralised andesite clasts are described by De Haan et al. (1933). This rock contains no calcareous components, and no fossils.

The whole rock may be pyritised and kaolinised in mineralised areas.

Grey quartzite and siltstone clasts may be derived from the Kuantan Formation metaquartzites described in this quadrangle (Rock et al., 1980). These clasts contain subangular to subrounded, equigranular quartz grains, in a matrix of fine quartz and clay minerals. Some grains show pressure solution contacts.

Other quartzite clasts consist of unsorted subangular to subrounded quartz grains with a clay mineral matrix.

Specimens collected from near the Rambutan Vein show no direct evidence of hydrothermal alteration, though the presence of altered feldspar grains in a few clasts may indicate that they are derived from altered andesitic material such as described by De Haan et al. (1933). Near a few of the other veins hosted in this rock, the hydrothermal alteration has resulted in bleaching, and some kaolinisation.

Phyllitic clasts can be identified by the presence of micas with higher birefringence colours, and a parallel alignment of some of the micas, with in some cases the micas wrapped around quartz grains in an augen structure.

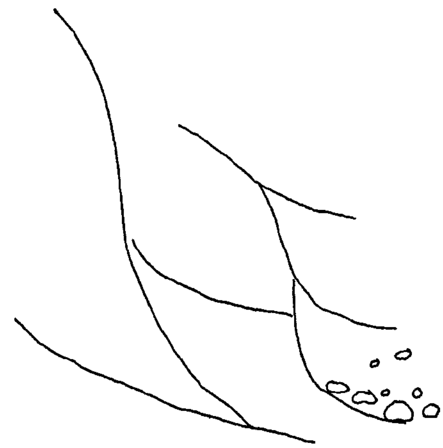
Fine slaty clasts are also present.

Quartz grains in some of the metamorphosed clasts show evidence of strain, with undulose extinction, and the formation of sub grains.

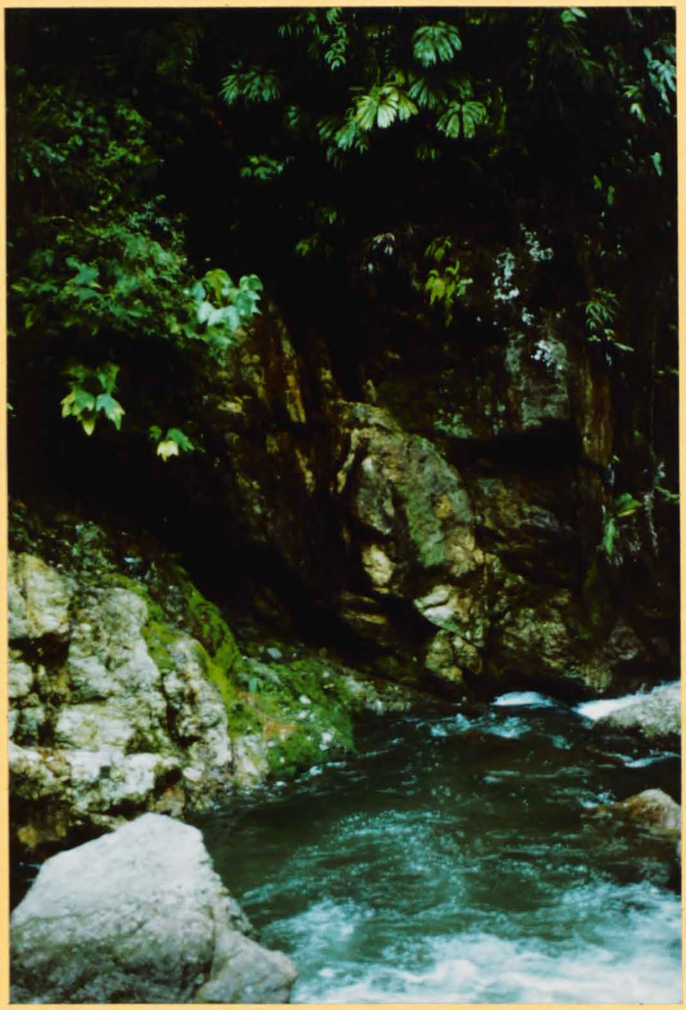
Some micaceous clasts show evidence of a second episode of deformation by the presence of kink bands, while in one case a similar history of multiple

Plate 3

a/ Outcrop of Brani Conglomerate, showing channelling.



b/ Photomicrograph of Brani Conglomerate, showing a phyllitic clast from the Kuantan Formation, and a conglomeratic clast with a phyllitic matrix (R69a).



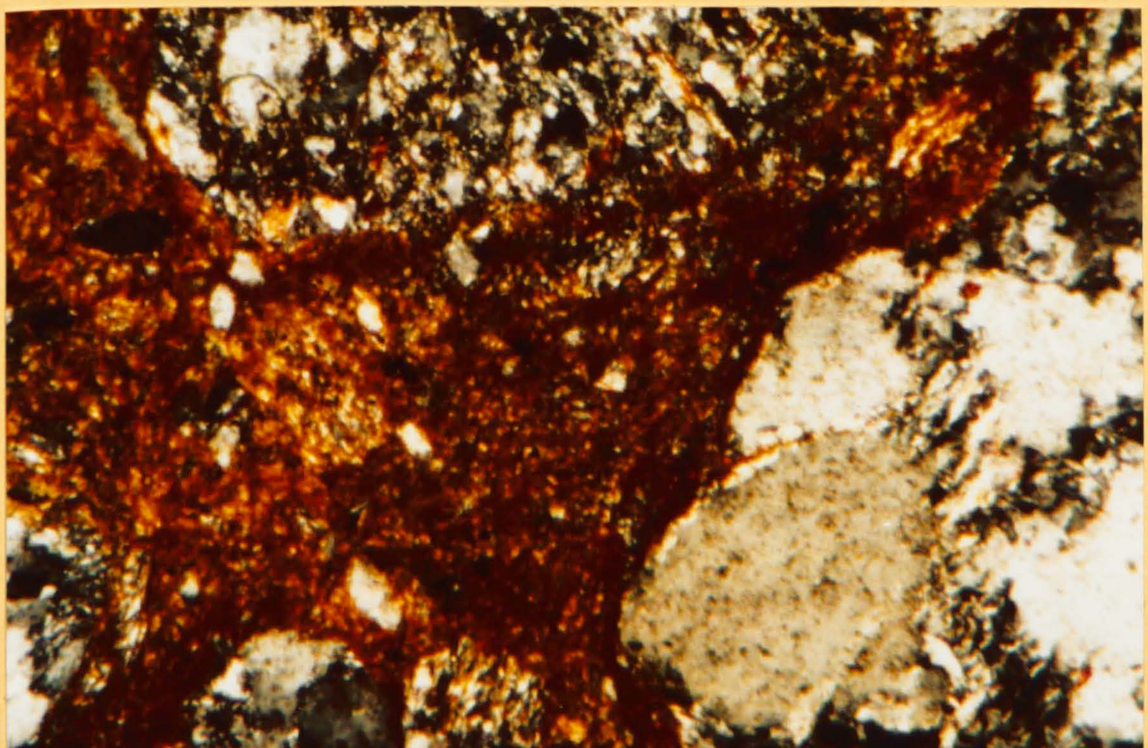
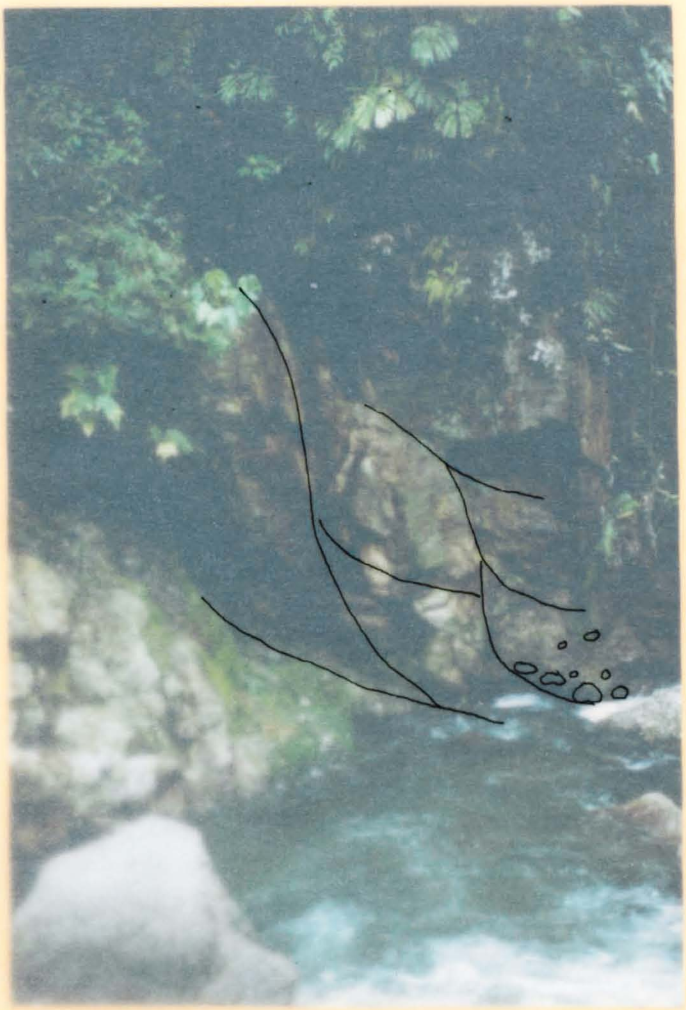
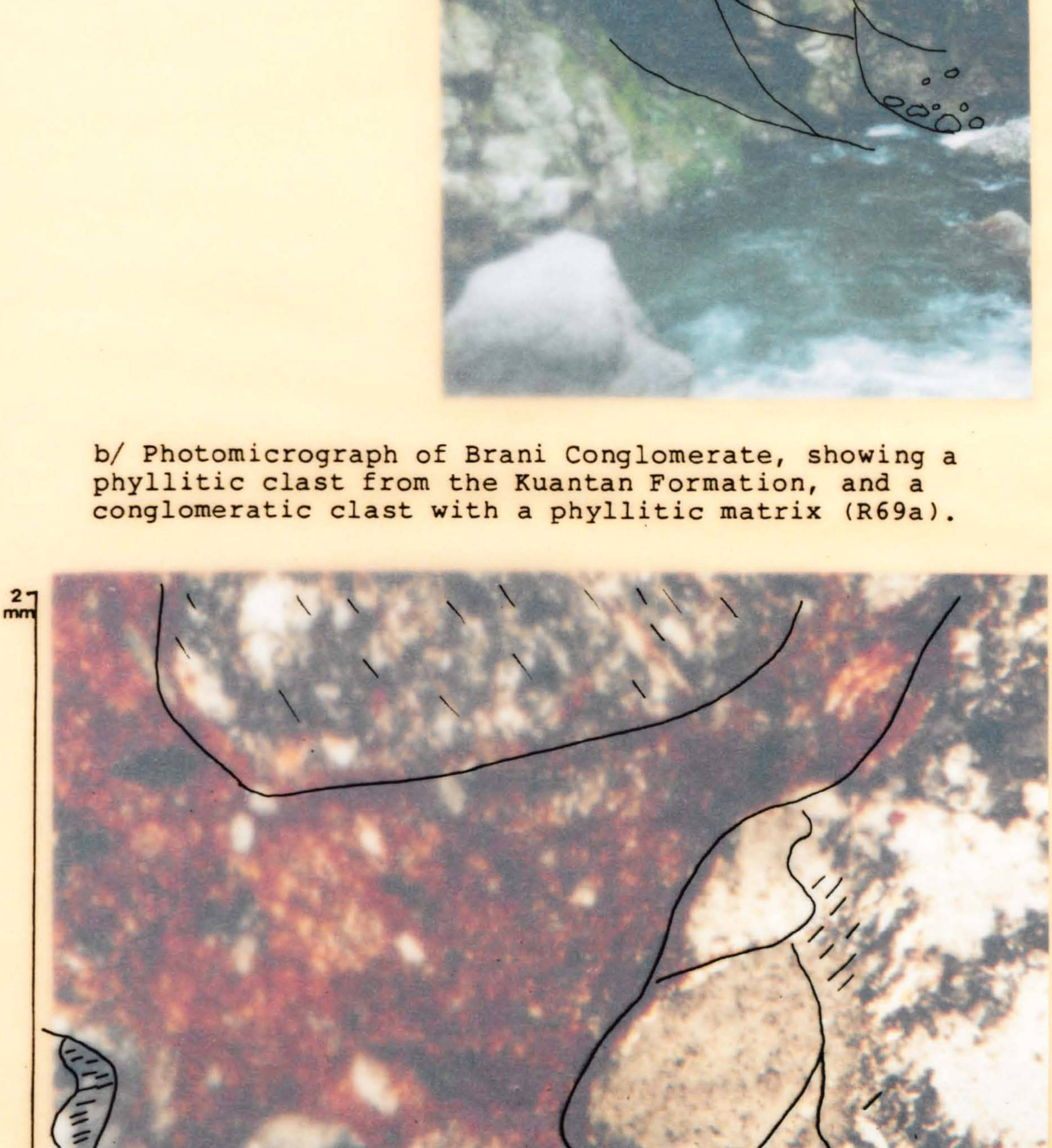


Plate 3

a/ Outcrop of Brani Conglomerate, showing channelling.



b/ Photomicrograph of Brani Conglomerate, showing a phyllitic clast from the Kuantan Formation, and a conglomeratic clast with a phyllitic matrix (R69a).



deformation with intervening erosion can be deduced from the presence of conglomerate clasts with a fabric in the matrix, but containing phyllitic clasts, each with a different orientation. Some of the phyllitic clasts are themselves conglomeratic. The edge of one of these clasts can be seen in the photomicrograph in Plate 3b.

The matrix of the conglomerate is fine red, yellow, brown or grey mud, which in thin section can be seen to consist of ill-sorted quartz grains in a limonitic or haematitic mud. In some cases the matrix is pale grey in colour, but may have been bleached as a result of hydrothermal alteration.

A thin coal layer is described by De Haan et al. (1933) from within the hydroelectric tunnels below the Brani vein. A specimen of red siltstone was found in these tunnels during the present investigation, and suggests that the coals described are interbedded with finer material, possibly in a lacustrine environment.

In the area immediately adjacent to the Mangani Mine, beds are 1-2m thick, and conglomerates contain clasts up to 15cm in diameter, but further to the west, in the old hydroelectric tunnels, bedding is not so massive, and red siltstone beds occur. As the Brani Conglomerate generally dips to the SW at 10-30°, the rocks in the Brani HEP tunnel may be stratigraphically higher, suggesting that the sequence becomes finer upwards.

The total thickness of the Brani Conglomerate is not known, but De Haan describes Brani Conglomerate outcropping at the top of the B. Kulit Manis at 1160m, and in the A. Paraman Tjigak at 300m, suggesting a thickness of over 800m. The conglomerate is not folded, though this apparantly thick sequence may be affected by vertical fault movement.

The Brani Conglomerate was originally described in the Mangani area, this being the host rock for the Brani vein. Rock et al. (1980) have assumed that this rock unit is of equivalent age to the Miocene Sihapas Formation conglomerates, and have shown these rocks as one unit on their map. However near Suliki at Tandjoeng Pandan typical quartz conglomerates from the Sihapas Formation can be seen directly overlying the pre-Tertiary (De Haan et al. (1933), suggesting that the Brani Conglomerate does not represent the basal beds of the Sihapas.

The rocks to the SE of the Mangani area, e.g. in the Harau canyon have also been mapped as Brani Conglomerate by the Indonesian Geological Survey (Solok Quadrangle, Kastowo and Leo 1975). However the conglomerates exposed at that point are different, containing mainly white quartz pebble clasts similar to those occurring in the Sihapas Formation conglomerates, and no metamorphic clasts, though iron staining gives it a similar red appearance to the Brani Conglomerate. One possibility is that the red conglomerates outside the Mangani area are lateral facies variations of the Sihapas Formation conglomerate, while the Brani Conglomerate in the Mangani area is older. Another possibility is that the Brani Conglomerate formed at a similar time to the Sihapas Formation, but some distance away, and has been brought into the Mangani area by strike slip faulting. However, the presence of grey quartzite clasts similar to the Kuantan Formation quartzite, which outcrop 10 km to the NW of Mangani, suggests that the Brani Conglomerate may be locally derived.

Clarke et al. (1980) describe coarse breccio-conglomerates and sandstones interbedded with red clays and mudstones, with locally derived clasts and thin coal seams in the Pematang Formation in the SW part of the Pakanbaru quadrangle. They suggests that these rocks are of equivalent age to the fresh-water Sankarang Formation in the Solok Quadrangle south of the equator (Kastowo and Leo, 1975), and equivalent to the Brani Conglomerate. Clarke et al. (1980) propose that after late Oligocene uplift and erosion, rifting of the back arc and Barisan area resulted in deposition of continental, sometimes red bed sediments in local troughs and grabens (Pemantang, Brani and Sankarang Formations). Turner (1983) suggests a similar local origin for coarse sediments in the area to the north of Mangani.

Attempts were made to determine the age of the Brani Conglomerate by Tan Sin Hok (Department of Mines, Bandung, reported in De Haan et al. (1933) using micro fossils, but were unsuccessful. During the present study no specimens containing dateable material were found. De Haan et al. (1933) consider these rocks to be of Eocene or Oligocene age, and compare them with the breccia group e_1 described by Verbeek (1883). De Haan also suggests that they may be similar rocks to the conglomerates at Oeloe Ajer described by Von Steiger (1920), or the breccia/marl group described by Musper (1929). Musper's breccia/marl group, like the Mangani Conglomerate occurs as an isolated outcrop, and cannot be correlated with any other group.

In the absence of direct evidence for the age of the Brani Conglomerate, the relationship of this unit to the Sihapas Formation, and to the unit south of the equator mapped as Brani Formation, cannot be determined. However the common occurrence of coarse, local deposits in the Oligocene suggests that the Brani Conglomerate may be of equivalent age.

In conclusion the Brani Conglomerate formed as a coarse river deposit in a local depression, in a continental environment.

2.2.1 Sihapas Formation.

Table 1 shows a comparison of the nomenclature used by different workers for the Tertiary deposits of Sumatra. The usage of Rock et al. (1980) has been followed in this account, rather than those of Coster (1974), or P.T. Caltex (Wongsosantiko, 1974). P.T. Caltex give the name "Sihapas", group status, and divide the unit into a number of formations. The Mangani area lies at the edge of the known Sihapas outcrop, and probably only a very restricted part of the sequence is exposed.

Table 1

<table>
<tr><th colspan="3">Rock et al. (1980)</th><th colspan="2">P.T. Caltex
(Wongsosangtiko, 1976)</th><th colspan="2">Coster (1974)</th></tr>
<tr><td>QUATERNARY</td><td colspan="2">MINAS Fmn</td><td colspan="2">MINAS Fmn</td><td colspan="2">NILO Fmn</td></tr>
<tr><td>TERTIARY 111
SUPERGROUP</td><td colspan="2">PETANI Fmn</td><td colspan="2">PETANI Fmn</td><td colspan="2">KORINTJI Fmn
BINIO Fmn</td></tr>
<tr><td rowspan="3">TERTIARY 11
SUPERGROUP</td><td rowspan="3">KAMPAR GROUP</td><td>TELISA Fmn</td><td colspan="2">TELISA Fmn</td><td colspan="2">TELISA Fmn</td></tr>
<tr><td>SIHAPAS Fmn</td><td>SIHAPAS
GROUP</td><td>Duri Fmn
Bekasap Fmn
Bangko Fmn
Menggala Fmn</td><td>SIHAPAS
GROUP</td><td>Tualang Fmn
Lakat Fmn</td></tr>
<tr><td>PEMATANG
Fmn</td><td colspan="2">PEMATANG Fmn</td><td colspan="2">KELESA Fmn</td></tr>
</table>

In the northern part of the area, beyond the graben edge, the sequence consists of very clean quartz conglomerates and quartzites with 0.4-2m thick beds. The quartz conglomerates consist of rounded white and clear quartz clasts (maximum diameter 3 cm), with a quartzite matrix. Sporadically slate or phyllite clasts are present, or grains of apatite. The phyllitic clasts (Plate 5a) suggest that the rock contains locally derived material from the Kuantan Formation.

Higher up the succession bedding becomes thinner, and consists mainly of sandstones and fine grey siltstones. A few thin tuff bands are also present. Plates 4a and 4b show outcrops of the Sihapas Formation quartzites.

Float in the streams leading away from the northern margin of the Mangani Graben invariably contains large boulders of coarse conglomerate, but rarely contains boulders of finer grained quartzites, although finer material is more common in outcrop. This may be due to the more durable nature of the coarser sediments, and suggests that examination of float does not always give a good picture of the rock types present in a river basin.

Generally the Sihapas Formation is only exposed at

Plate 4

4a/ Outcrop of Sihapas Formation, showing how the resistant nature of the rocks has resulted in the formation of gorges.

4b/ Outcrop of finer grained Sihapas Formation, showing channelled and laminated sediments.

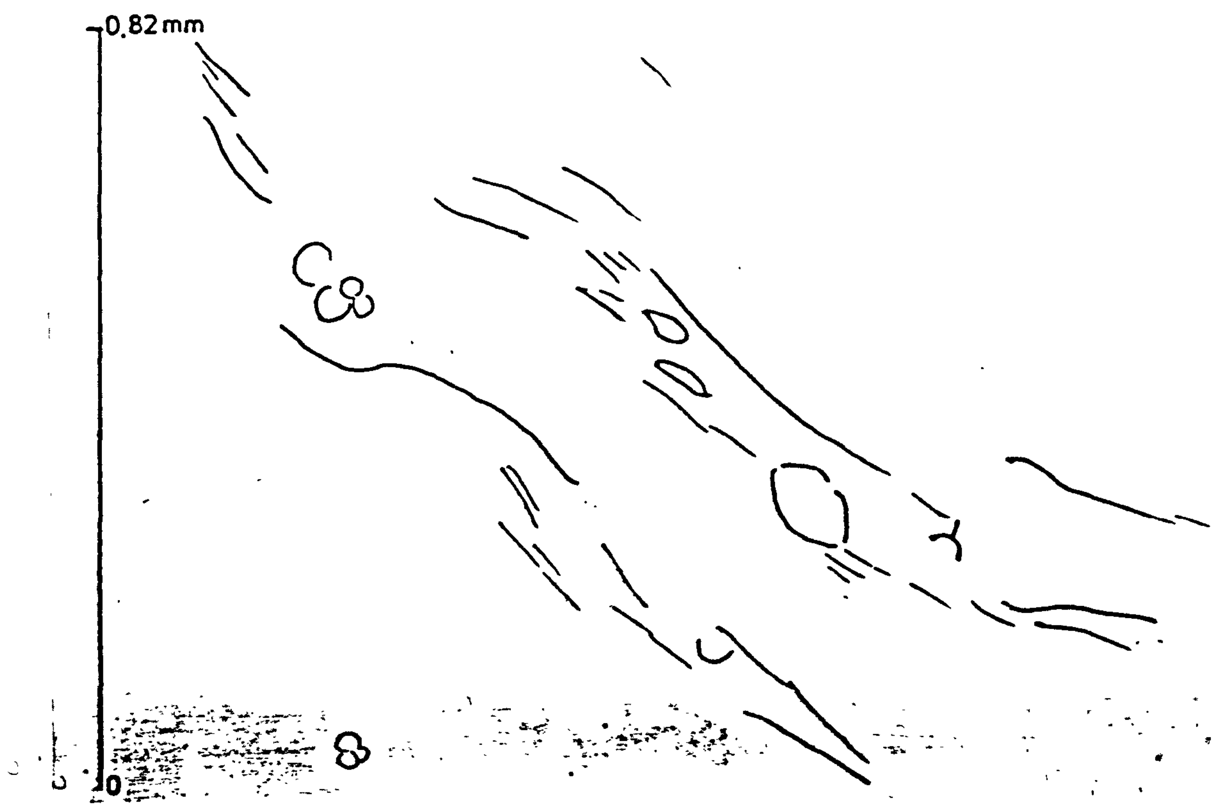
Plate 4

4a/ Outcrop of Sihapas Formation, showing how the resistant nature of the rocks has resulted in the formation of gorges.

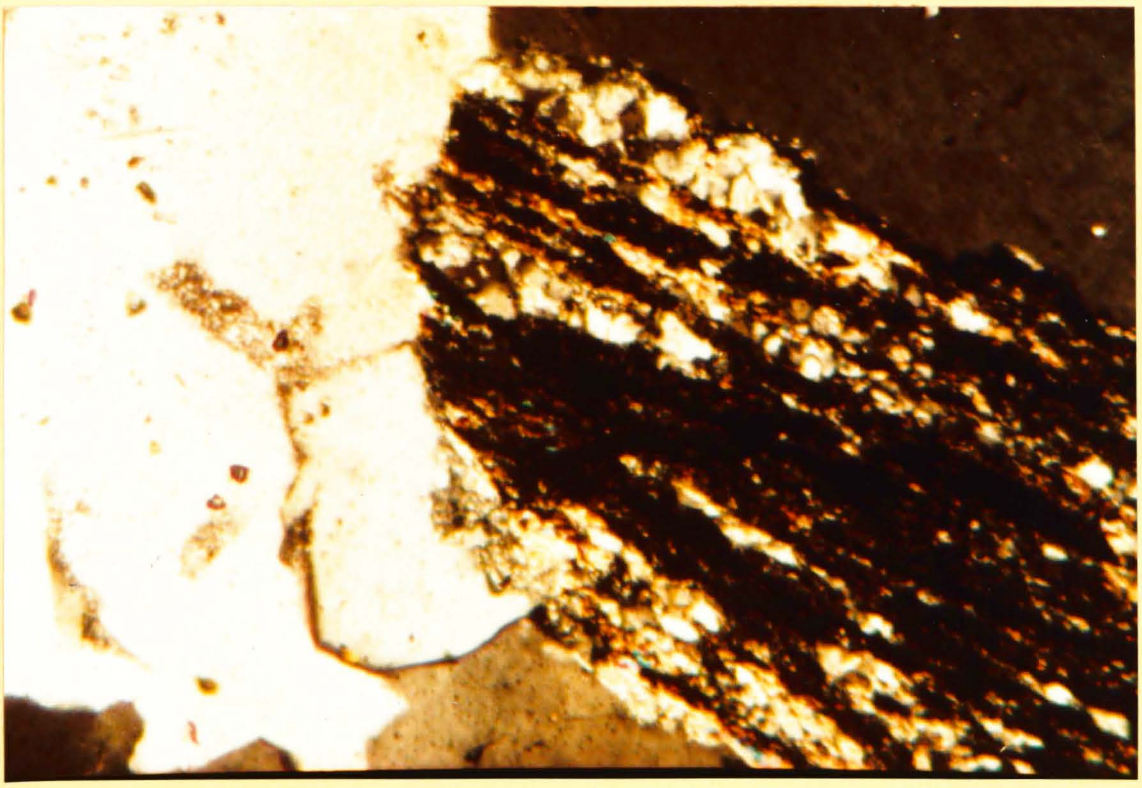
4b/ Outcrop of finer grained Sihapas Formation, showing channelled and laminated sediments.

Plate 5

5a/ Photomicrograph of a phyllitic clast, possibly from the Kuantan Formation, in a specimen from the Sihapas Formation (Ma R53a).



5b/ Photomicrograph of a specimen of deformed calcareous, carbonaceous, foraminiferal siltstone from the Telisa Formation (Ma R829).



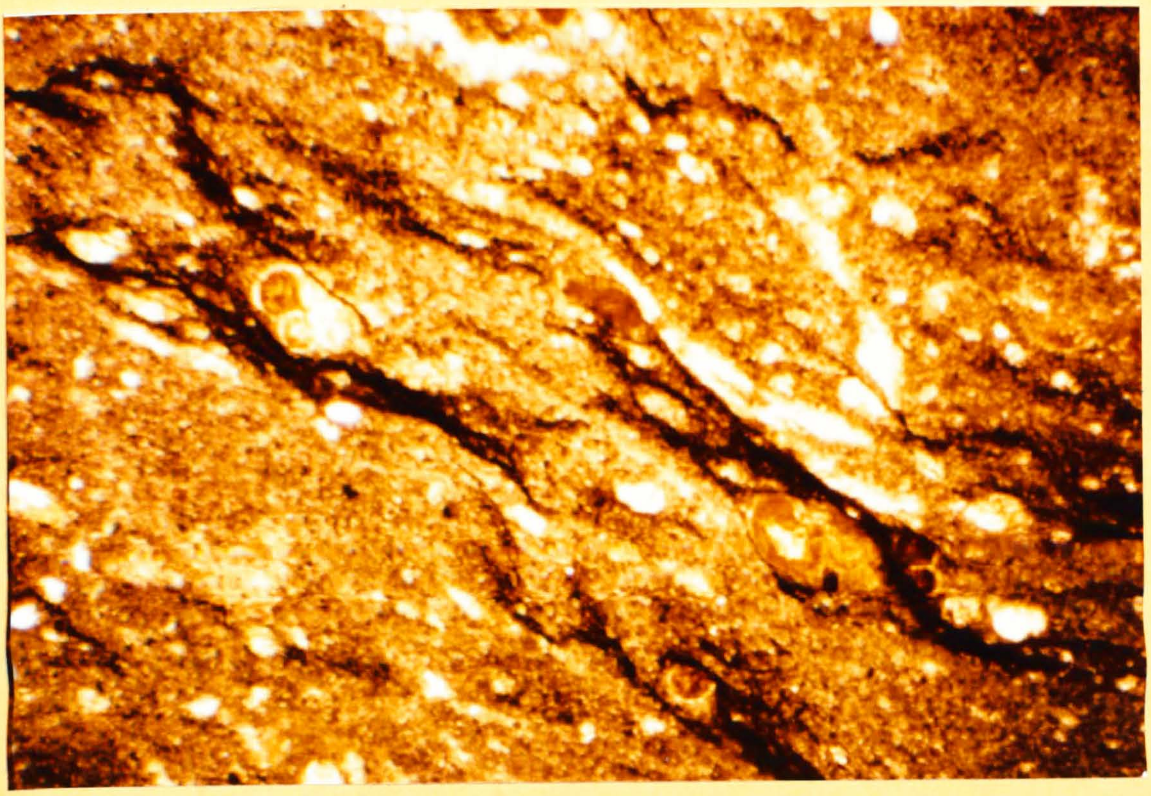
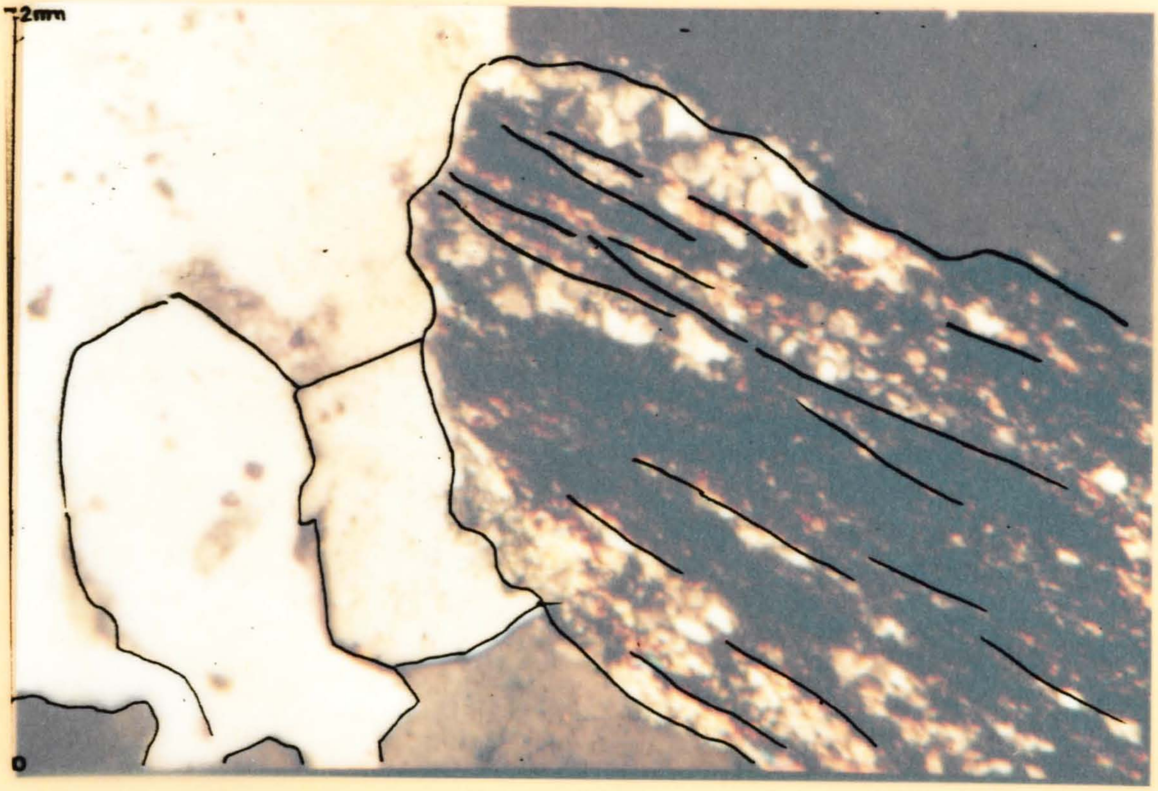


Plate 5



5a/ Photomicrograph of a phyllitic clast, possibly from the Kuantan Formation, in a specimen from the Sihapas Formation (Ma R53a).

5b/ Photomicrograph of a specimen of deformed calcareous, carbonaceous, foraminiferal siltstone from the Telisa Formation (Ma R829).

the northern edge of the Mangani Graben, but in the east of the area Sihapas Formation quartzites are also exposed within the graben.

The thickness of this succession exposed at Mangani does not exceed 60m, but neither the base, or the boundary with the Telisa Formation is exposed, both boundaries probably being faulted.

The Sihapas Formation sediments dip gently to the west (maximum dip 25^{o}), and are unfolded.

Examination of thin sections shows that grains are generally sub-rounded to rounded, sub-spherical to spherical. This texture, as well as the very pure nature of the sand, gives evidence of a very high energy near shore environment, with the conglomerates possibly representing beach deposits. Calcite is not present either as grains or cement. In a few cases grains of chert are present. Some specimens have a high porosity, though in most cases pressure solution and secondary silicification has resulted in an almost massive quartz rock, with a superficial resemblance to vein quartz. In a few cases a small amount of mica is present in the matrix, forming wavy bans in pressure solution seams.

Elsewhere in Sumatra the thickness of the Sihapas Formation is large (>1000m), and sandstones from the Sihapas Formation have been extensively drilled and mapped in the central Sumatra basin, as they are the resevoir rocks to oil.

The Sihapas Formation has been described by De Coster (1974) and Kamili et al. (1973), as well as Cameron et al. (1980). These deposits formed as the result of a Miocene marine transgression, and in the Central Sumatra Basin pass up conformably into the deeper water Telisa Formation.

Clarke et al. (1980) concluded that part of the Sihapas Formation was derived from the west, suggesting that part of the Barisan mountain area was emergent. The presence of locally derived clasts from the Kuantan Formation, and the nature of the sediments, suggests that the shoreline may have been near the Mangani area.

The Sihapas Formation sediments seems to have formed as shallow water beach deposits, with later, finer sediments being formed in deeper water as the transgression developed.

2.2.3 Telisa Formation.

Above the quartzites are grey and black mudstones, black cherts and siltstones, and bituminous sandstones. In some cases these rocks are calcareous. Each of the river sections that crosses the graben and cuts through these rocks shows a slightly different sedimentary succession. Similar rocks also occur, presumably downfaulted, within the northern part of the graben area.

The coarser sediments (bituminous sandstones and the grey mudstones) occur mainly within the western part of the graben area. This suggests that these rocks may occur higher in the stratigraphic sequence than rocks immediately above the quartzites. Similar rocks are described by De Haan et al. (1933) from the base of the lower river valleys in the western part of the Mangani area. These include fine blue grey rocks with fine calcareous laminations, dark blue grey shales, slightly coarser dark grey bituminous shales, sandy and calcareous rocks containing mica and pyrite. In the eastern part of the Mangani Graben very altered grey mudstones with some siltstone layers occur.

Stratigraphically above the Sihapas Formation are dark grey or black siltstones, some so silicified that in the field they look like grey or black cherts or fine grained basalts. These rocks are exposed in both branches of the Galanggang river. Grey mudstones and sandstones occur in the upper part of the Rambutan (Botung Lawas) river, to the north of a quartz porphyry intrusion, and may again be coarser sediments higher in the sequence. Black silicified siltstones occur near the Serassah Vein in the most eastern part of the area.

In the north-western part of the area in the upper part of the A. Rumput Pait black pyritised mudstones are interbedded with bleached tuffs, indicating the start of the Miocene volcanicity.

Float from the A. Moempas to the west of Mangani consisted of an agglomerate with limestone clasts, suggesting that true limestones may overlie the carbonaceous and calcareous sediments described.

A number of specimens contain foraminifera, but are very altered. One specimen consisted of foraminiferal limestone which had been completely replaced by quartz, and now looks like a pale grey chert. In a number of cases forminifera have been replaced by pyrite or calcite. Two specimens were examined by the British Museum (Adams, personal communication). The fossils are Tertiary in age, with the absence of Guembelina suggesting a Neogene age, though no accurate date has yet been obtained. These age determinations are not in conflict with the ages known for the Telisa Formation. Plate 5b is a photomicrograph of a deformed Telisa Formation specimen.

During the time when the Mangani mine was open some specimens were examined by Rutten, who found Globigerina, rare Textulariidae, a few small Rotaliidae, and no large foraminifera. This suggested a Mesozoic or Tertiary age. Terpstra also examined these rocks and found a Lepidocyclina indicating a Miocene-Pliocene age. These results are reported in De Haan et al. (1933).

Telisa Formation rocks are described as occurring in the most northern part of the Mangani mine by De Haan et al. (1933). Carbonaceous and calcareous siltstones and layered mudstones are described, containing foraminifera (Lagena and Globigeriniidae).

In the Mangani Graben Telisa Formation sediments are occasionally highly brecciated, and near the Rambutan Atas Vein appear to be dipping vertically, though this may be an illusion as a result of silicification along vertical joints. To the north of the graben, in the few cases where outcrops were not immediately adjacent to faults, the bedding is undisturbed, with shallow dips to the SW.

The Telisa Formation sediments may have formed in restricted anaerobic waters , with some sediment input. Such an environment may have been lagoonal, as the emergence of the Barisan mountains may have commenced at that time.

2.3 Upper Tertiary to Recent lithologies in the Mangani area.

Filling the Mangani Graben, and also deposited on top of the sedimentary rocks on either side are a number of different types of extrusive volcanic rock, occasionally interbedded with sediments, and intrusive dykes and irregular bodies. Due to the highly altered nature of the rocks in some localities, the original nature of the rocks cannot always be recognised. In the field the most obvious means of classifying the volcanics is according to colour, though hydrothermal alteration has resulted in very pale bleached rocks, and the formation of green epidote and chlorite. In addition the different lithological types of tuffs and agglomerates can be found interbedded with each other, and outcrops of a particular lithology may be scattered throughout the Mangani area. This suggests that a number of different volcanic centres were producing material at the same time, in a similar way to the present situation in West Sumatra.

Volcanic rock units have been classified by the amounts of the different lithologies present. These lithological types are described in the next section, and then the different volcanic groups are described.

As well as extrusive tuffs, lavas and agglomerates, a number of intrusive igneous bodies are present. Some of the very small outcrops of medium grained intermediate and basic rocks are difficult to relate to the geological history of the area, though they are likely to be the coarser grained equivalents of the lava flows and dykes associated with the volcanics.

2.3.1 Extrusive volcanics at Mangani

a/ Pale grey tuff.

Fine to coarse pale grey lithic or crystal tuff, occasionally containing up to 40 % feldspar megacrysts, is scattered throughout the area. Generally the composition is intermediate, though rocks are often highly altered, so that recognition of the original petrology is difficult. Remains of multiple twinning suggests that in most cases the feldspar is plagioclase. In some cases the cores appear to be more highly calcic, containing more secondary calcite. In some cases grains of quartz are present, but appear to be of sedimentary origin, and in one case tuff grades into volcanogenic sandstone. The high degree of alteration makes the distinction between tuffs and lavas difficult, but none of the samples appear to contain relict flow banding in the matrix, suggesting that there are no lava flows related to these tuffs. Some samples are more acid, and contain both primary and secondary quartz, but these rocks are also some of the most highly altered, suggesting that the pale grey colour is the result of alteration. Generally the proportion of coarser grained material is low. These features suggest that this may be related to a volcanic centre at some distance away, which was producing intermediate rocks. Rock et al. (1980) describe a suite of intermediate volcanic rocks related to the Amas volcanic centre, 15 km to the NE of Mangani, and suggest that some of the Mangani volcanics are derived from this source.

b/ Fine green-grey tuff.

This type of tuff is usually very fine grained, and highly altered, so identification of the mineralogy is difficult. Some samples contain the remains of scattered feldspar crystals, and patches of chlorite, presumably the alteration product of ferromagnesian grains. In some cases the rocks have a marbled appearance suggestive of sedimentary structures. The fine nature of this tuff type suggests that these rocks are distal, possibly airfall tuffs. These rocks may possibly be the fine grained products from the Amas volcanic centre.

c/ Grey agglomerate/breccia.

In some cases this material appears to be a fault breccia. The high degree of alteration makes the distinction between true agglomerates and lahars difficult, as the finer grained matrix is usually totally altered. I have used the term agglomerate for all volcanic rocks containing large fragments, though in analogy with the modern Indonesian volcanoes, most of such material is probably the result of a lahar. If coarse material is produced by a volcanic mud flow, then rocks need not be proximal, as modern lahars move large blocks for 10's of kilometers.

d/ Green crystal tuff with abundant feldspar megacrysts.

This material is probably the equivalent of the green lithic tuff, but the distinctive green and white mottled appearance of the rock, and its relative abundance merits its inclusion in a separate group. Feldspar megacrysts can make up 50% of the rock, though in most cases they consist of up to 30% of the rock. In some cases the feldspar consists of good crystals up to 3mm in length, but broken grains are more common. Ferromagnesian megacrysts may originally have also been present, but are invariably altered to patches of chlorite or epidote and opaques. In some cases the epidote is the manganese variety thulite, distinguishable in hand specimen by its pink colour. The Mangani Vein contains abundant manganese, and the presence of thulite suggests that the regional alteration and mineralisation are related. In a few specimens crystal outlines are still recognisable, and indicate that in these cases the ferromagnesian mineral was an amphibole. Feldspar in most cases appears to have been plagioclase, though in some cases orthoclase may have been present.

f/ Green tuff.

Generally fine to coarse grained lithic tuff. In the field feldspar is not noticeable, but in thin section feldspar grains up to 1mm in length are common. Finer feldspar laths present in the groundmass of some specimens suggests that the weathering and alteration have made it difficult to distinguish in the field between tuffs and lava flows, as both have a similar granular appearance when weathered. Sphene and apatite grains are sometimes present, and are relatively unaltered. Feldspar is usually plagioclase, and may be highly zoned, the zoning being picked out by the varying degrees of alteration. Overall the composition appears to be intermediate, and this lithology is often interbedded with andesite.

g/ Red tuff.

Outcrops of red lithic tuff are rare, and in thin section the alteration results in an appearance very similar to all the other volcanics at Mangani. This rock frequently occurs as a component in agglomerates, or as the matrix.

h/ Red and green agglomerate.

This rock type is particularly common in the area to the east and south of the Mangani Vein, and is sometimes seen interbedded with shales. Green and red lithic tuffs described previously can either occur as clasts, or make up the matrix, suggesting that these lithologies were simultaneously available. Some samples undoubtedly formed as lahars, but in a number of samples an andesitic lava matrix is recognisable.

i/ Dark grey basic tuff and agglomerate.

This lithology is not common, but in the eastern part of the area dark tuffs and agglomerates with pale feldspar or dark ferromagnesian grains occur. In some cases alteration is of limited extent, suggesting that these were deposited after the main phase of hydrothermal alteration. Pyroxene is abundant, occasionally being pale brown, suggesting the presence of augite. Olivine is occasionally still recognisable. Agglomeratic rocks have a very fine grained, almost glassy matrix, and contain both basic tuff and basalt fragments.

j/ Acid tuffs and breccias.

Restricted to the SE of the area mapped, are very pale rocks consisting of pumice fragments and quartz crystals, with occasional biotite flakes. The associated acid breccias contain tuffaceous material, as well as clasts of slate material, apparently derived from the pre-Tertiary Kuantan slates, and carried up by the lava.

2.3.2 Types of lavas and dykes at Mangani.

These are often more identifiable than the tuffs, as the lower porosity has restricted the degree of alteration.

k/ Andesites.

These are characteristically green tinted, though some samples petrologically identifiable as andesitic are dark blue or red tinted. In most cases the groundmass is very fine grained, with feldspar laths aligned in a flow-banded or trachytic texture. Plagioclase is frequently zoned, but where alteration is limited plagioclase can be recognised as oligoclase or andesine. Some samples consist of quartz-andesite, and patches of chlorite appear to replace pyroxenes and amphiboles in other samples.

Hornblende-andesites, augite-andesites and biotite andesites are described from within the Mangani mine (De Haan et al. (1933), though the descriptions of the extent of alteration suggest that the names amphibole and pyroxene-andesites are more appropriate.

l/ Dacites and micro-granodiorites.

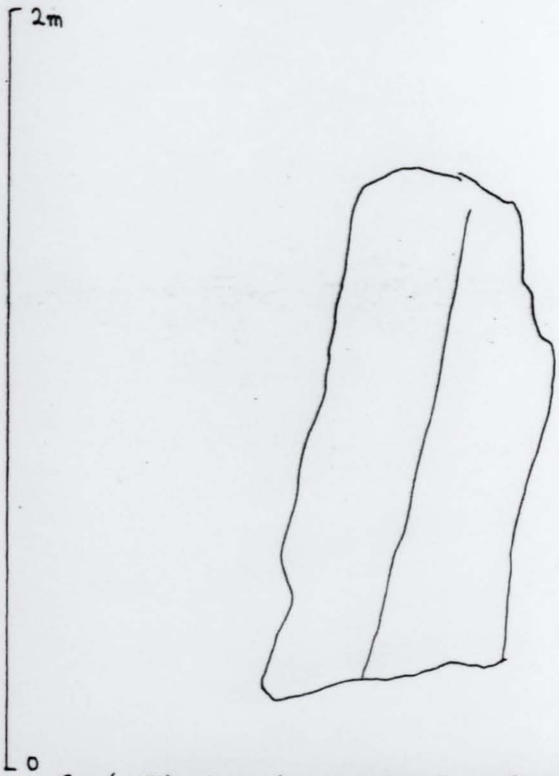
These rocks are also often highly altered, but the presence of quartz and the relative proportions of the feldspar types allows these rock types to be distinguished in some cases. Micro-granodiorite sometimes shows an almost graphic texture. In hand specimen these rocks are usually grey coloured, or buff or pinky grey. In a few cases the medium grained rocks are very dark in colour due to the very high percentage of dark coloured feldspar, the rock consisting of almost 80% feldspar (Plate 6a). The feldspar is andesine in all cases where it could be recognised.

Liparites and dacites are described from within the Mangani mine by De Haan et al. (1933). They occur in the northern part of the mine, to the north of the Mangani Breccia. These are described as pale grey rocks with quartz and bleached biotite crystals. Feldspar has been totally altered. Apatite zircon and rutile also occur. Much of the quartz in the groundmass may be secondary.

m/ Basalts and micro-gabbros.

These lithologies usually occur as dykes, or irregular small intrusions. Basaltic float is particularly

Plate 6



6a/ Photomicrograph of relatively unaltered dacitic rock, showing large feldspar phenocrysts and trachytic texture (Ma R110).

6b/ Outcrop of Mangani Sediments, with black shale interbedded with lenses of tuff and tuffaceous sandstone.

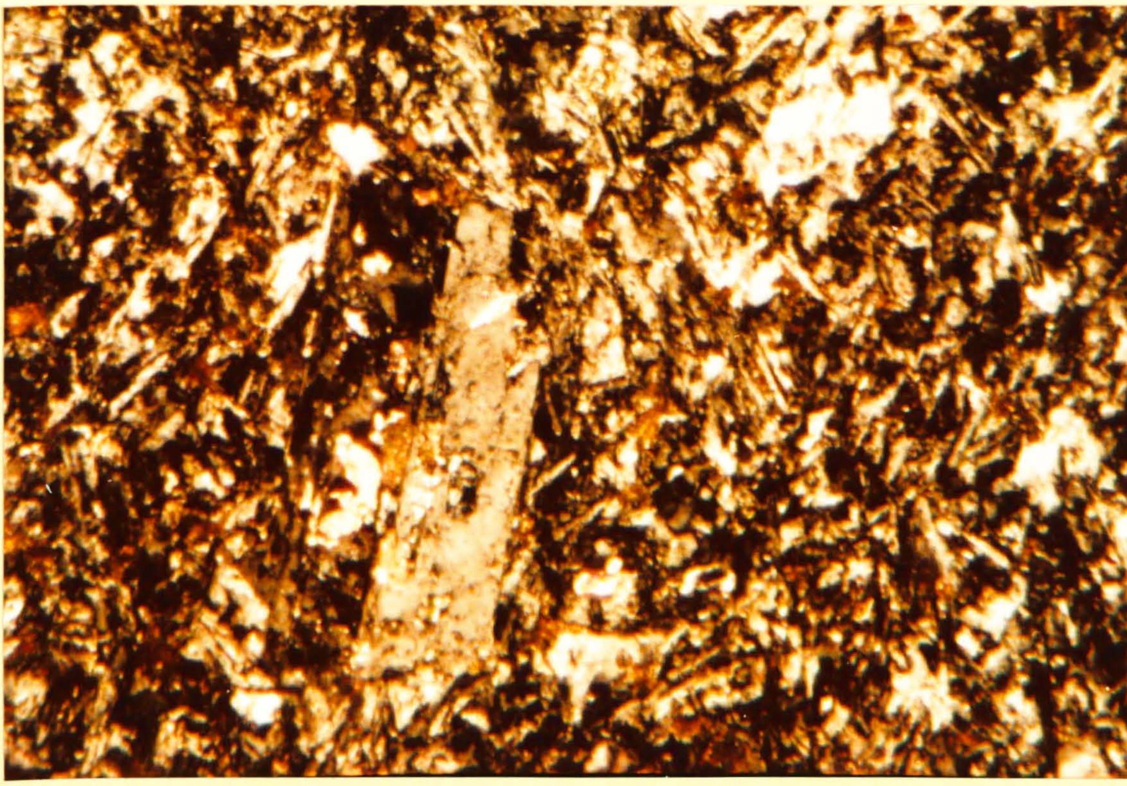
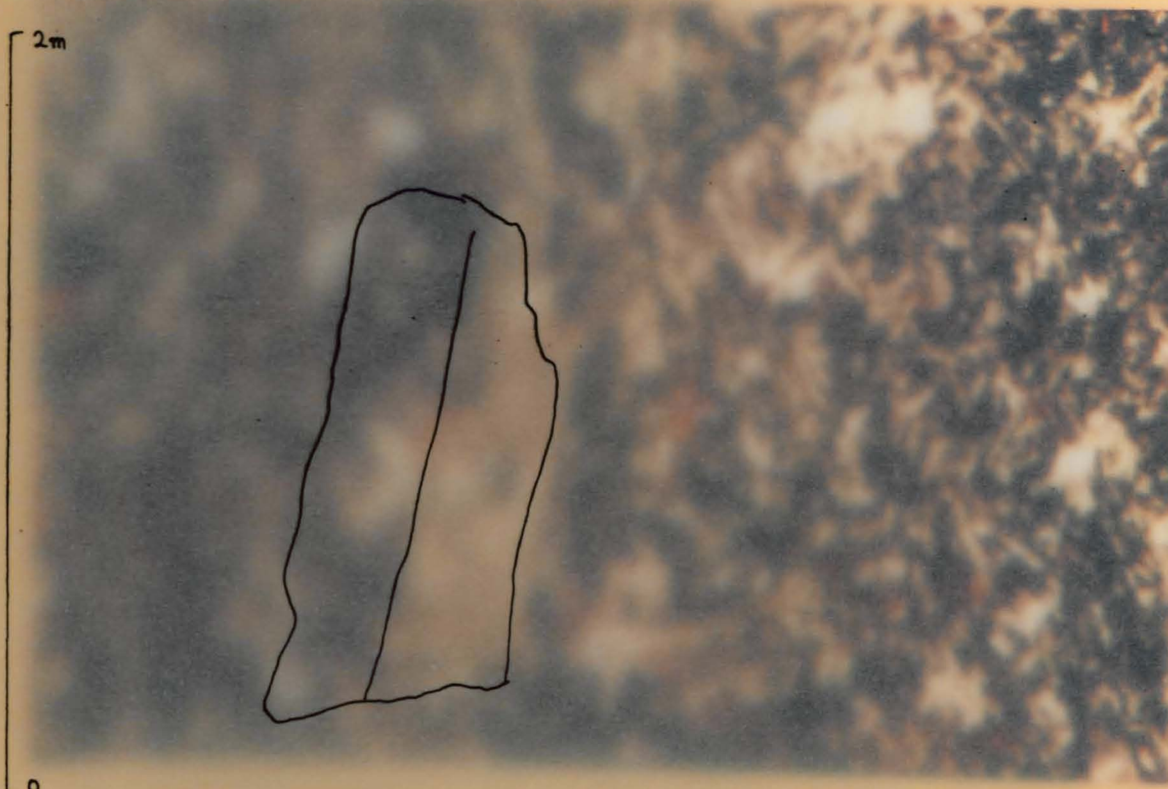


Plate 6



6a/ Photomicrograph of relatively unaltered dacitic rock, showing large feldspar phenocrysts and trachytic texture (Ma R110).

6b/ Outcrop of Mangani Sediments, with black shale interbedded with lenses of tuff and tuffaceous sandstone.

common in the east of the area. These rocks are unusual in that they are only slightly altered, suggesting that they were formed after the regional hydrothermal alteration. Olivine is often present, and clear pyroxene. Plagioclase is usually sodic.

Gabbroic rocks with plagioclase phenocrysts are described from within the Mangani mine by De Haan et al. (1933). Plagioclase consists of 60-70% An (bytownite). There is a complete gradation in size between the large plagioclase crystals, and the smallest plagioclase grains in the ground mass. As well as abundant plagioclase, the groundmass contains monoclinic pyroxenes, biotite and ilmenite. The groundmass contains some quartz grains, which may be secondary. In some cases feldspar grains are rimmed by ferromagnesian minerals, in a weakly ophitic texture. Apatite occurs in some samples. Rocks are altered, with uralitisation of feldspars being common.

Generally basic rocks are described from all parts of the Mangani Mine, while more acid rocks are restricted to the northern part of the mine.

As well as coarser basic rocks, hypersthene basalt is described from within the Mangani mine (De Haan et al., 1933). Phenocrysts of zoned plagioclase are sometimes surrounded by pyroxenes in an ophitic texture. The ground mass consists of plagioclase (bytownite) laths, with grains of monoclinic pyroxenes, biotite and opaques. Like other rocks these are highly altered.

Basalts are also found within the mine (De Haan et al., 1933), and are described as highly fractured, with pyrite filling the fractures, and generally altered. This suggests that some basaltic rocks were formed before the regional alteration, and some after.

The presence of characteristic lithologies has been used to define the following units, though it is clear that the volcanic centres from which the different tuffs and lavas originated were active at the same time. The units are described in approximate order of relative age, the age relationships also being shown in the stratigraphic column on the geological map (Enclosure 2).

2.3.3 Amas Volcanic Formation

In the North Sumatra Project Natal area report (Rock et al., 1980), a group of volcanic rocks related to the Amas volcanic centre is described, and the basic to intermediate rocks at Mangani are included in this category. The IGS nomenclature has been adopted in this work. Bukit Amas lies about 10km NE of Mangani. These rocks are considered to be the oldest of the volcanic units, as they appear to be interbedded with sediments from the upper part of the Telisa Formation in the A. Rumput Pait.

Generally the Amas volcanics consist of mainly intermediate and some basic agglomerates and tuffs and dykes. The Amas Volcanic Formation includes many of the grey coloured lithologies described above. Most of the rocks are fine or medium grained tuffs, and could be recognised in the field by the characteristic soft brown weathered appearance. Some of the agglomerates may in fact be lahars, which would explain why such coarse deposits occur so far from their source. The Amas volcanic centre appears to have been active for quite a long period, and may be the source of some of the more basic components found in the Mangani Volcanic Formation. Some of the intermediate and acid volcanics occasionally found interbedded with the more basic volcanics may be derived from the Mangani volcanic centre.

2.3.4 Mangani Volcanic Formation

These rocks are slightly younger than the Amas volcanics, though the Amas and Mangani volcanic centres may well have been active at the same time.

The Mangani volcanics can be distinguished by being far more varied in composition (acid-basic), containing red and green agglomeratic beds, green tuff and occasional shale and volcanogenic sandstone beds. The larger proportion of coarse deposits, and the presence of true agglomerates (rather than lahars) suggests that the erruptive centre was in the immediate vicinity. Agglomerates can be recognised by the presence of a chilled igneous matrix, while other rocks with large clasts have a more indeterminate matrix.

2.3.5 Mangani Sediments

Near the junctions of the Botung and Rambutan rivers, dark shale and a small amount of dirty tuffaceous sandstone occurs interbedded with the Mangani volcanics. The mudstone is either massive or finely banded, and grades into siltstone and volcanogenic sandstone, the grains in the coarser sediments sometimes being matrix supported. Banding is caused by the variation in content of organic material, which also occurs in irregular patches. In some cases banding is caused by a variation in grain size. Often the organic material is selectively pyritised. Coarser grained sandstones are fairly unsorted, with quite angular grains and a micaceous matrix. In some cases carbonaceous laminae are present in the sandstones.

In one sample pyritised foraminifera are present (Plate 7a), indicating that the rock is of marine origin.

The coarser sediment consists of lenses in some cases (Plate 6b).

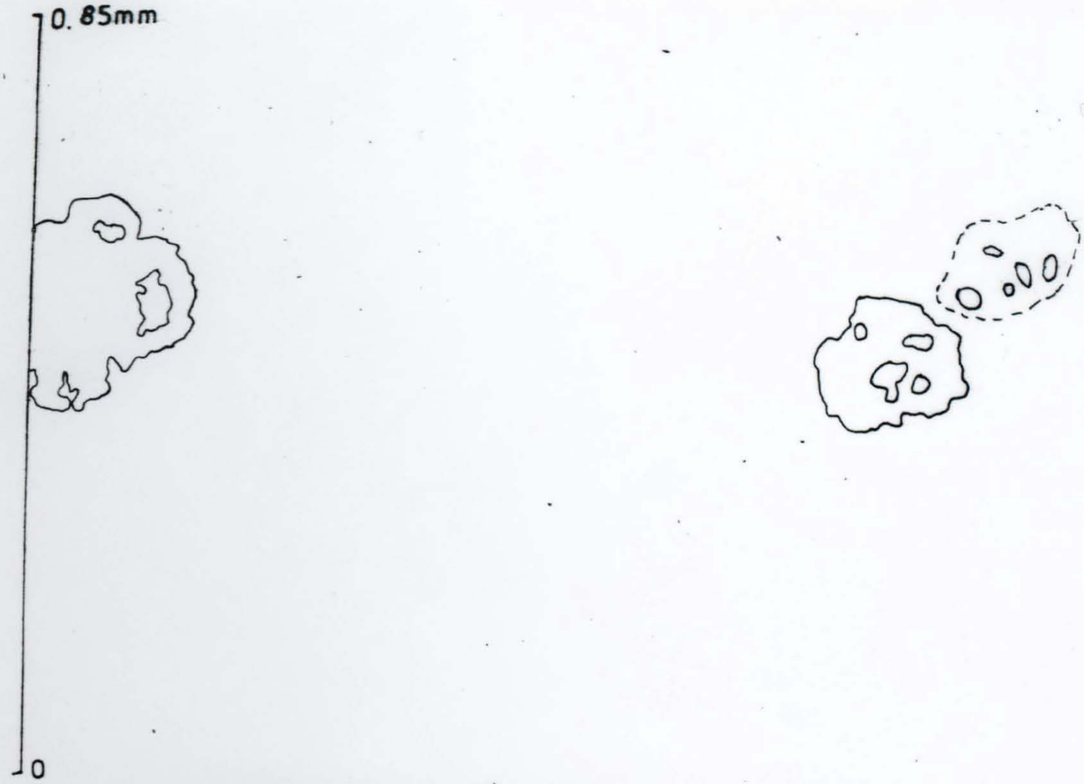
Like all other rocks in the Mangani area these rocks are often highly altered or brecciated, resulting in pressure solution, pyritisation and silicification.

The presence of a true agglomerate (rather than a lahar) cemented by a lava matrix, interbedded with these sediments suggests that for at least part of the time this area was terrestrial, though the presence of foraminifera suggests marine conditions. This suggests that the organic rich mudstones may have formed in lagoonal conditions.

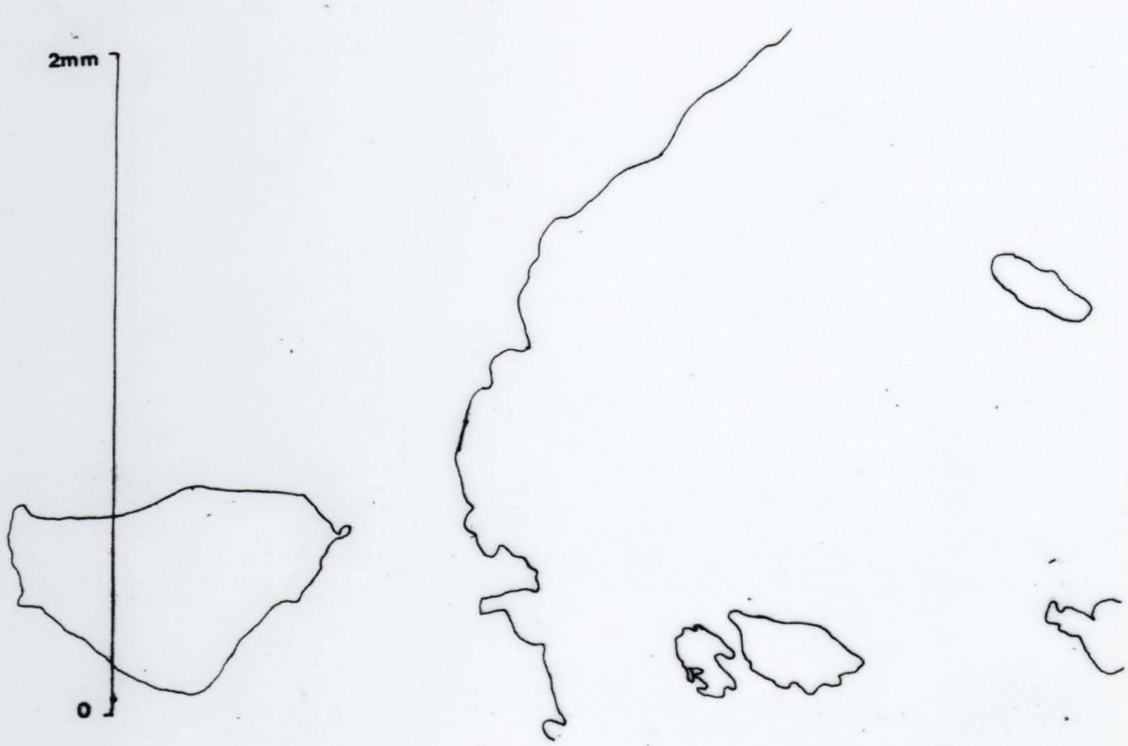
2.3.6 Mangani Conglomerate

The Mangani Conglomerate occurs at the southern graben edge. The rock is almost identical in appearance to the Brani Conglomerate, but contains mineralised volcanic clasts, and is interbedded with a few thin (30 cm) red fine tuff bands. This can be interpreted as a fault scarp deposit of mainly reworked Brani Conglomerate pebbles. The fine red tuff may represent the waning stages of volcanism

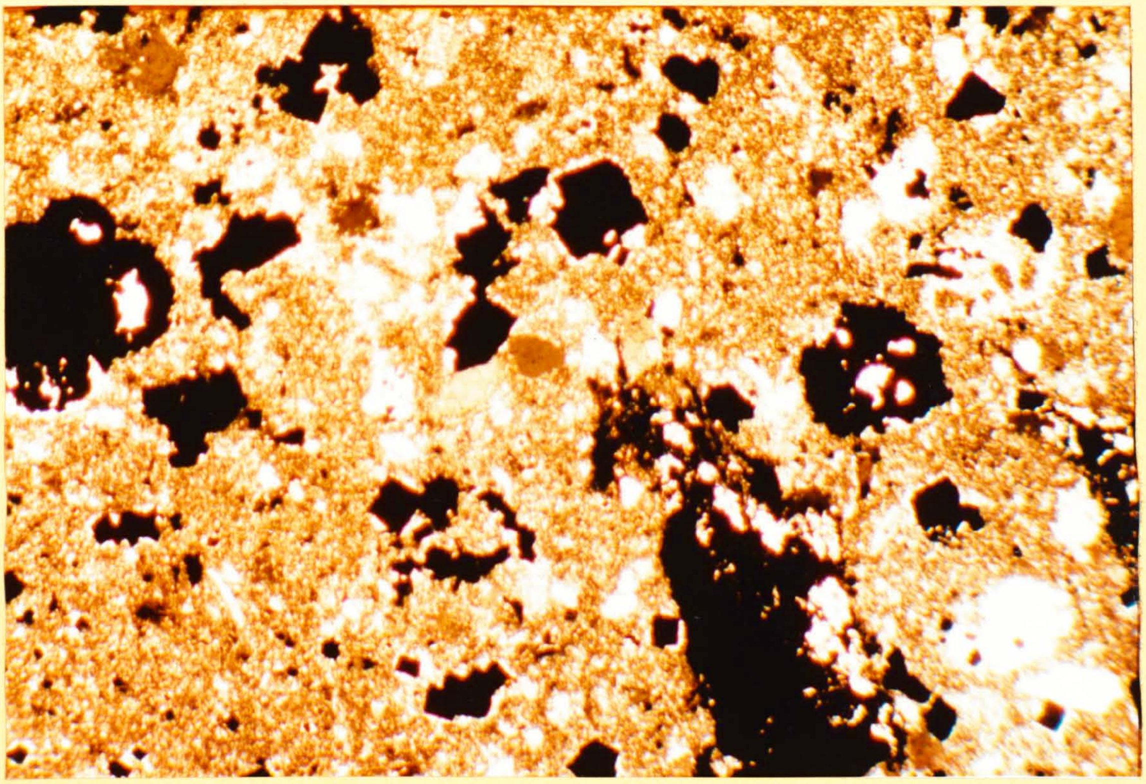
Plate 7



7a/ Photomicrograph of carbonaceous mudstone from the Mangani sediments, with pyritised foraminifera (Ma R28).



7b/ Photomicrograph of Mangani Breccia, with dark, chilled glassy matrix on the right hand side of the picture (Ma 8).



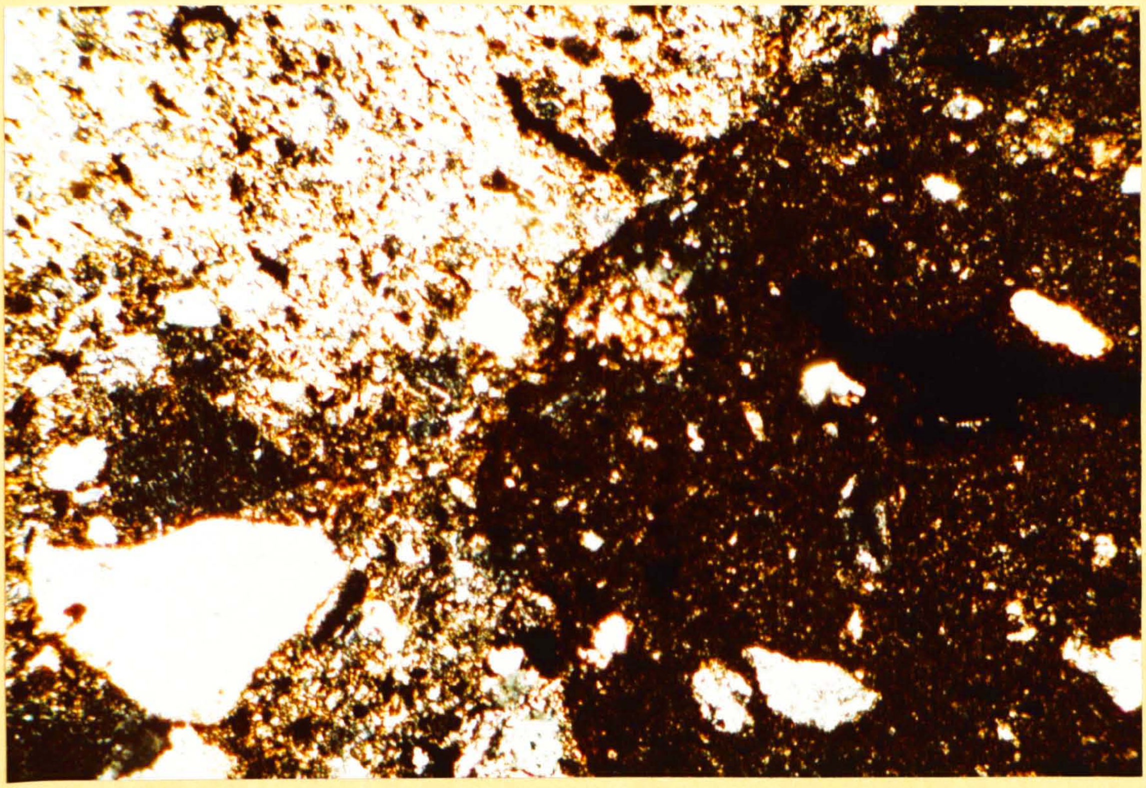
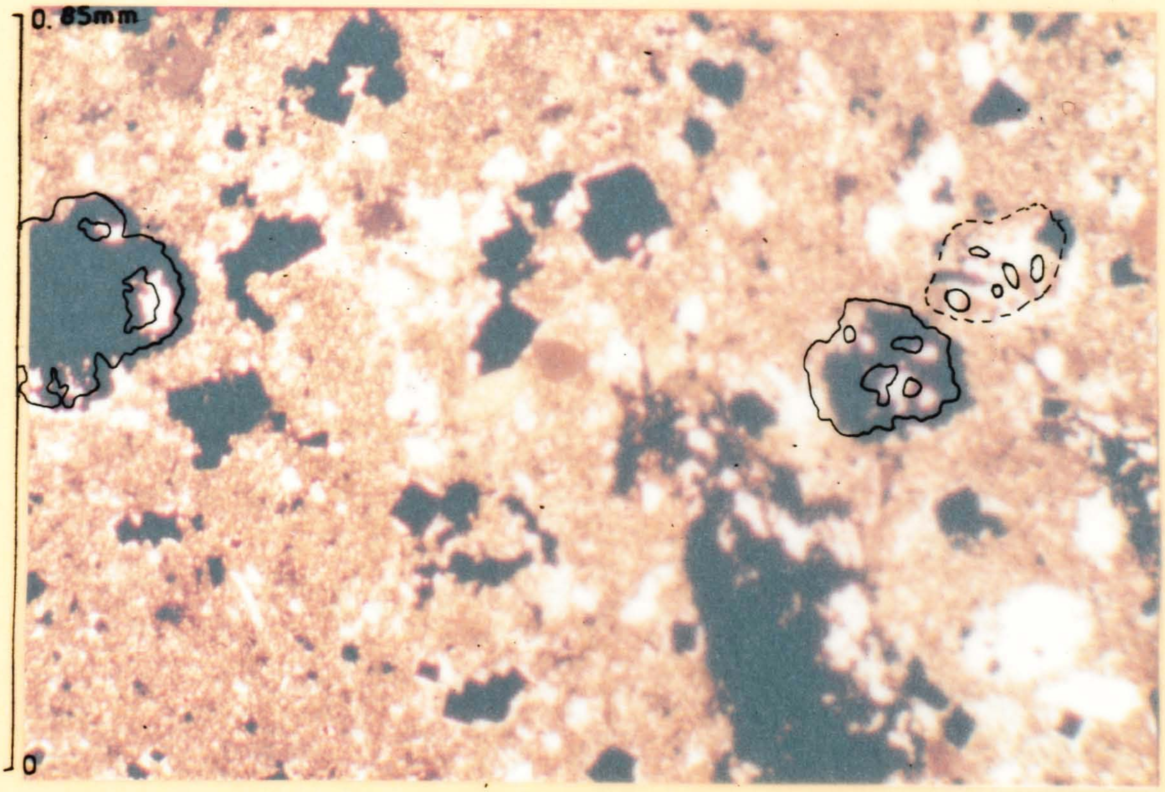
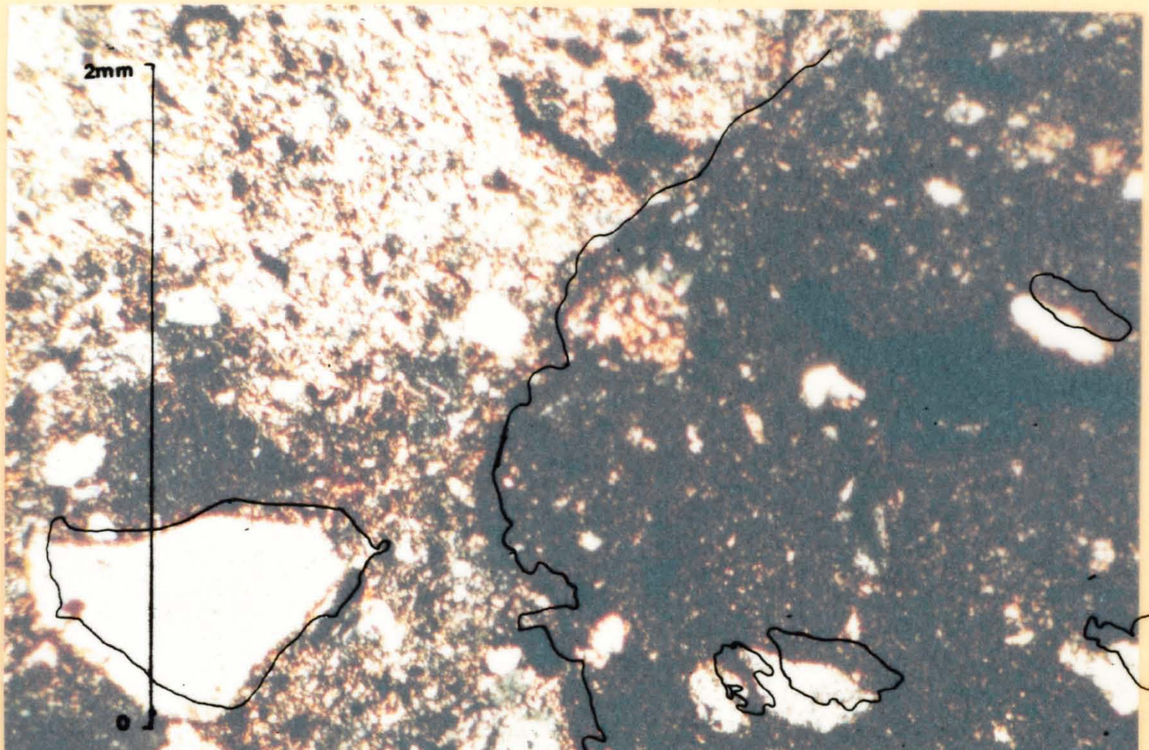


Plate 7



7a/ Photomicrograph of carbonaceous mudstone from the Mangani sediments, with pyritised foraminifera (Ma R28).



7b/ Photomicrograph of Mangani Breccia, with dark, chilled glassy matrix on the right hand side of the picture (Ma 8).

from the Mangani centre. It is not certain whether this unit formed before or after the mineralisation, as the mineralised volcanic clasts may have been selectively mineralised. In the past the two conglomerates have been mapped as the same unit.

Unfortunately all specimens of this rock type disintegrated in transit, so that it has not been examined in thin section.

2.3.7 Mangani Breccia

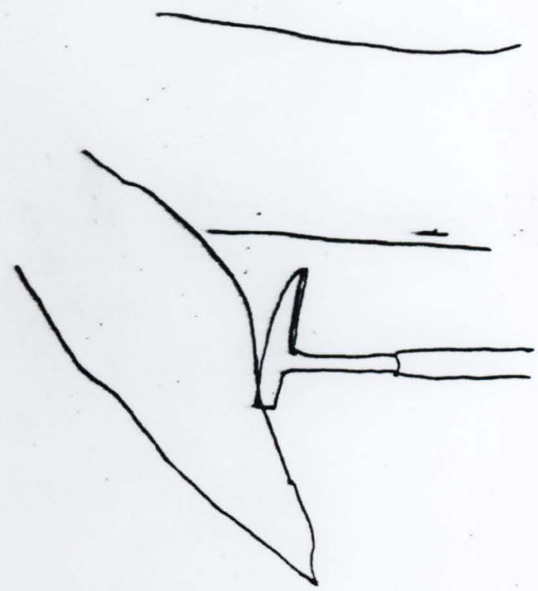
The Mangani Breccia is confined to the graben area, and here only outcrops as lenses varying in width from a few centimeters (Plate 8a) to a few metres (Plate 8b), intruded along faults and joints. These are marked on Enclosure 2, the geological map of the Mangani area, and also on Enclosure 3, the map of the Rambutan/Silver Vein area.

The breccia consists of small (<10cm) mostly angular fragments of shale, sandstone and tuff set in a glassy matrix. This can only be seen intruded into the Mangani volcanics so its age relationships with other rock types is unknown. Plate 7b is a photomicrograph of the Mangani Breccia, and shows the dark glassy matrix.

Within the Mangani mine, this breccia is described as an oval pipe like body 150-300m in diameter (De Haan et al., 1933). The edges of the breccia were intersected by the tunnels in the Mangani mine in three directions, giving a good indication of the shape and internal structure. The breccia pipe was found in tunnels over a vertical height of 340m. At its widest point the pipe does reaches a diameter of 300m, the pipe apparently being oval-shaped in a NW-SE direction. Clasts of volcanics and of the Telisa Formation are described from the breccia in the mine, though no material derived from the Brani Conglomerate had been recognised. Clasts are angular, unsorted, of all sizes. Layering was not found. The matrix consists of finely brecciated clast material, and chlorite, sericite, epidote, quartz and carbonate. By analogy with the less altered material collected away from the mine during the present investigation, this may well be altered glassy igneous material.

A similar breccia is described as the host to the

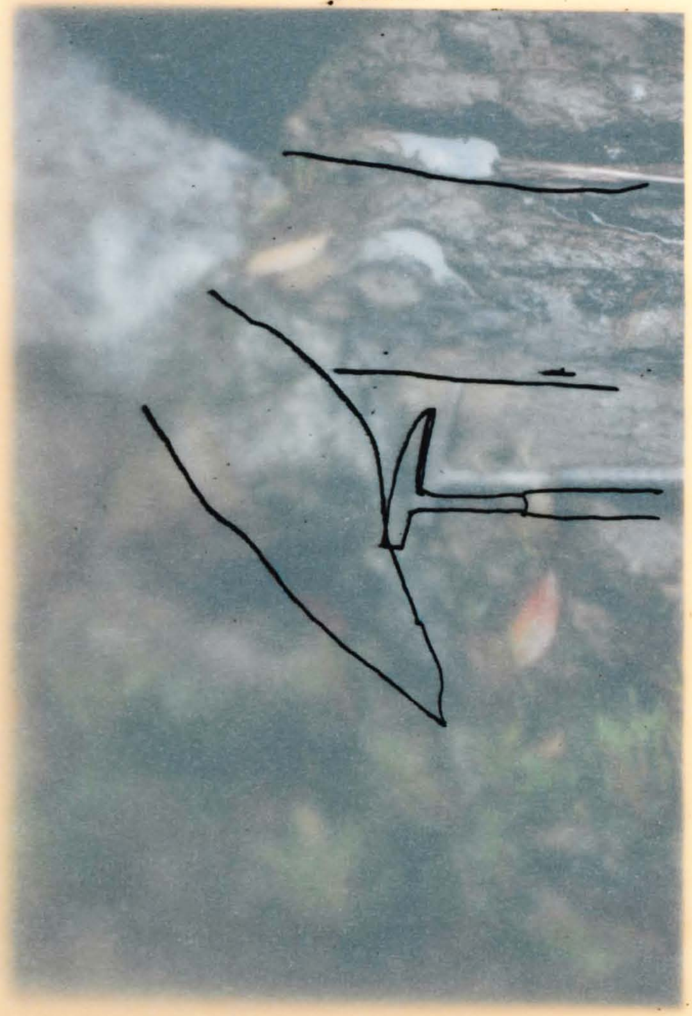
Plate 8



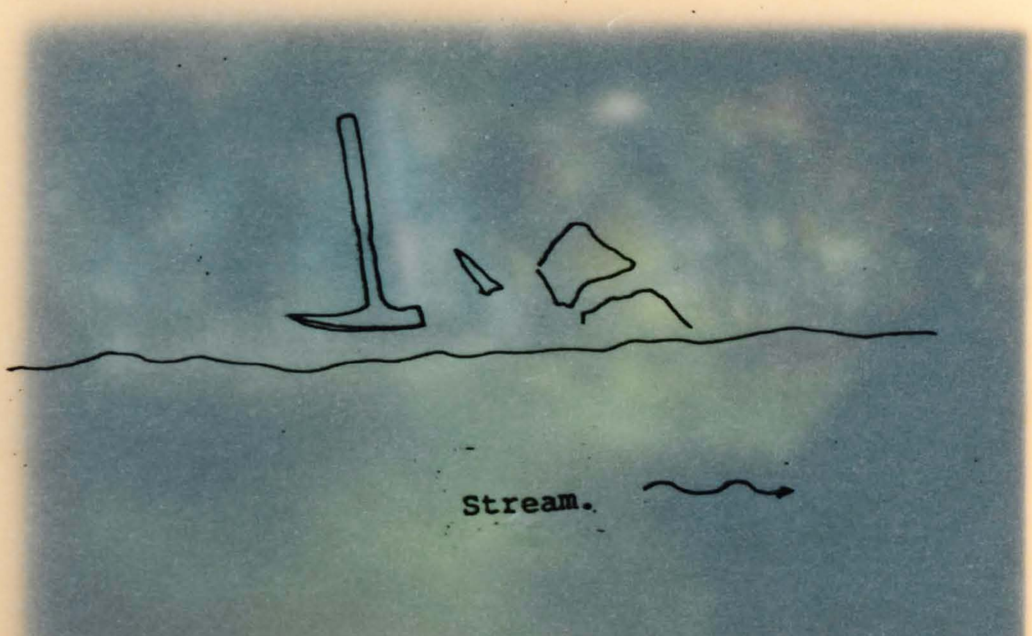
8a/ A small lens of Mangani Breccia, intruded into tuffaceous sandstones and black shales of the Mangani Sediments.

8b/ Part of a 3m dyke of Mangani Breccia, intruded along a fault zone in the A. Rumah Sakit.

Plate 8



8a/ A small lens of Mangani Breccia, intruded into tuffaceous sandstones and black shales of the Mangani Sediments.



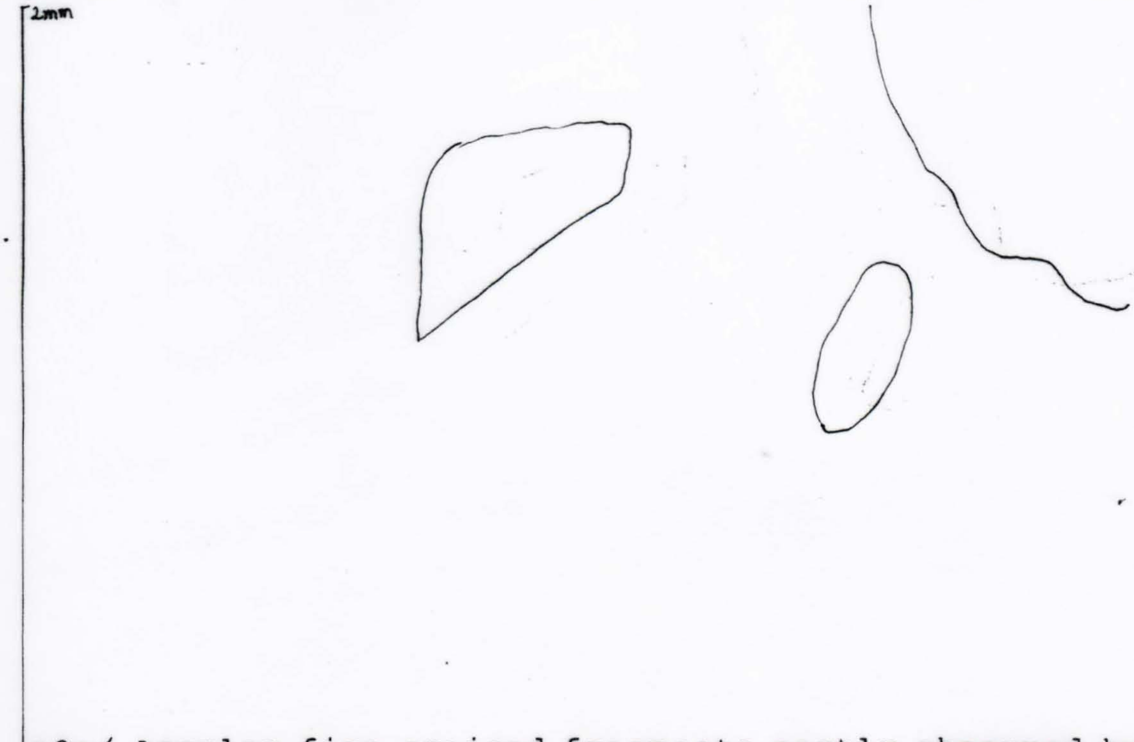
8b/ Part of a 3m dyke of Mangani Breccia, intruded along a fault zone in the A. Rumah Sakit.

mineralisation in the Balimbing mine (Grey 1935). Both the Balimbing and Mangani mineralisation was formed along fault zones. The origin of this type of igneous breccia is not clear, but the glassy matrix suggests very abrupt solidification. Possibly faulting resulted in pressure reduction, allowing magma to penetrate the fault zone, the magma having picked up pieces of the fault breccia during its abrupt ascent, before it solidified. The sporadic presence of this material as thin lenses over a large area suggests that a large body of magma was available to be tapped.

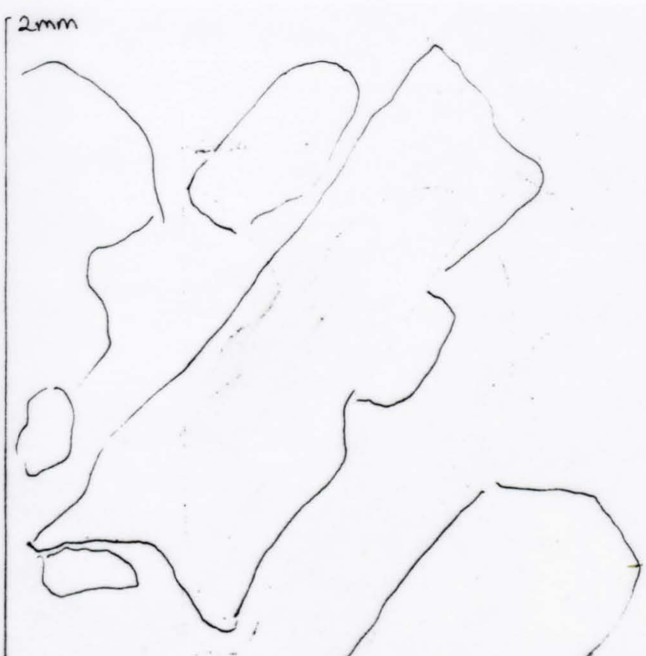
2.3.8 Feldspar porphyry/Tuff dykes

In almost all cases these dykes are so altered that recognition of the lithology is impossible. These dykes are identical in appearance to some of the more acid bleached tuffs with abundant feldspar megacrysts, visible both in the field, and in thin section (Plate 9b). These rocks are not considered to be normal lavas, as the megacrysts show abundant evidence of abrasion. Angular fine grained fragments are also sometimes present (Plate 9a). These are also not normal tuff beds, as dyke shaped bodies can be seen intruding both into quartzites, and into older volcanics, and these dykes clearly demonstrate cross-cutting relationships. In most cases the rock consists totally of carbonate, sericite or kaolinite, and quartz, with ghosts of the larger grains still visible. In extreme cases these rocks are so silicified that they grade into massive quartz reefs. Significantly many of the mineral veins are either partly hosted within such a dyke, or the mineral vein itself contains remnant blocks of partly altered tuffaceous material, suggesting that at least part of the vein material formed as a result of metasomatic alteration of such dykes, rather than as a space filling deposit. Dacite dykes reported as occurring adjacent to the Rambutan and Silver Veins by Boomgaart (1949) may be similar, and some of the tuff dykes are mentioned as feldspar porphyries by De Haan et al. (1933).

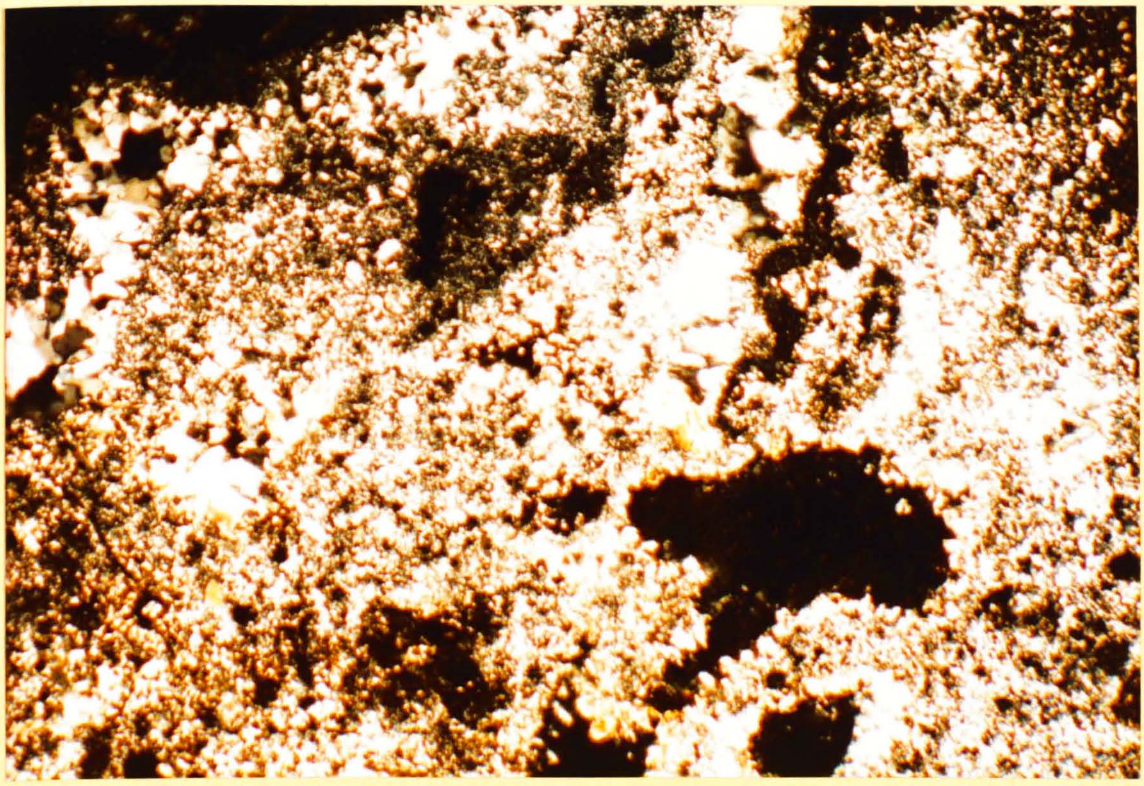
Feldspar porphyry dykes are also mentioned in the literature from other mineralised areas in Sumatra, e.g. Balimbing (Grey 1935), Salida (Westerveld en Uytenbogaart, 1948), Lebong Simpang (Hovig 1914),

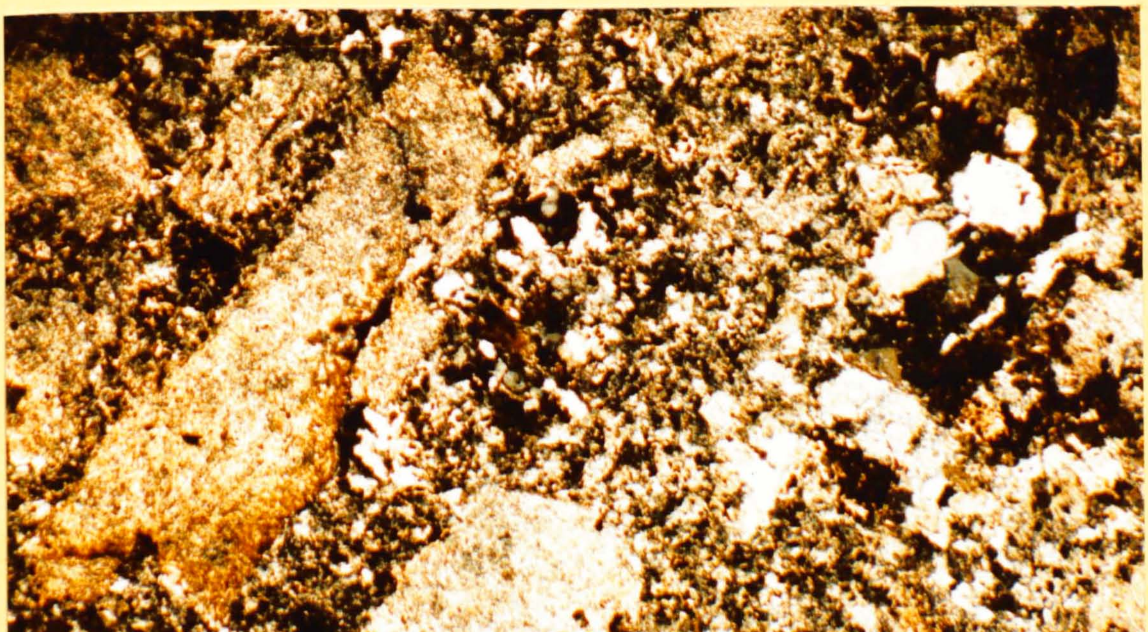


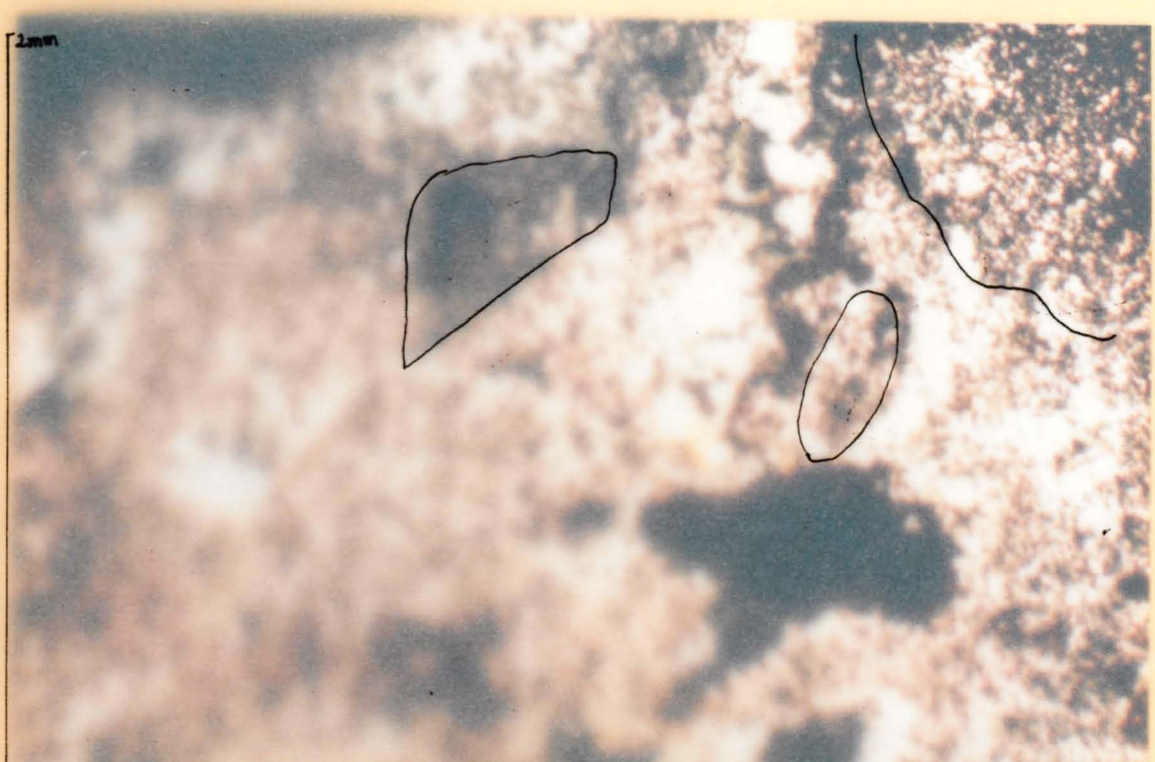
9a/ Angular fine grained fragments partly obscured by hydrothermal alteration in a tuffisite dyke (Ma R848b).



9b/ Altered feldspar megacrysts in a tuffisite dyke associated with the Gorge Vein.







9a/ Angular fine grained fragments partly obscured by hydrothermal alteration in a tuffisite dyke (Ma R848b).

9b/ Altered feldspar megacrysts in a tuffisite dyke associated with the Gorge Vein.

Tambang Sawah (N. Wing-Easton, 1926) and Rejang Lebong (Zwierzycki, 1936). This suggests that there may be a genetic relationship between such dykes and the mineralisation

Tuff dykes and pipes, or tuffisites have occasionally been reported in the literature, e.g. Coe (1966), where they are interpreted as being caused by fluidisation phenomena, and are discussed in relationship to the carbonate phases of kimberlitic intrusions. At Mangani no tuffisite pipes have been recognised, though an igneous breccia pipe is present.

All of the tuff dykes recognised are located along faults, and it is considered that during faulting, the abrupt reduction in pressure could allow gases to escape from magma, and the gases could carry fragments of chilled magma, feldspar phenocrysts, and fragments of country rock up the fault.

The significance of these dykes is further discussed in the concluding chapter.

2.3.9 Mangani Porphyry

In the northern part of Mangani are scattered small exposures of quartz porphyry. These may be part of a larger, still buried intrusion, and genetically related to the Mangani Volcanics and the mineralisation. This lithology occurs as a larger intrusion in the upper part of the S. Botung Lawas, where the massive appearance and large area of outcrop may have lead to this being decribed as a granite. A similar large intrusion occurs in the S. Botung, below the Serassah Vein. In thin section the rock consists of a very fine grained matrix with quartz plagioclase and some orthoclase phenocrysts. Locally the rock has a graphic texture and is very similar to some of the micro-granodiorites found in other places at Mangani. In hand specimen the rock is very pale green, with visible white grains, and patches of dark material which is chlorite replacing the ferromagnesian minerals. This rock is not as highly altered as some of the other rocks in Mangani, but the presence of pyrite suggests that this rock has also been affected by the regional alteration.

2.3.10 Basalts

The unaltered nature of basalt dykes present in the area suggests that they formed after the hydrothermal alteration. Basalt dykes have been found cutting the Amas and Mangani Volcanics, though generally such dykes are not common. Some basaltic rocks are highly altered, and are probably earlier, related to the Amas Volcanics. Basalt float is common in streams draining the eastern part of the area suggesting that larger outcrops of basaltic material may be present.

2.3.11 Guntung Volcanics

The youngest rocks in the area are the Guntung Volcanics, which consist of acid tuffs and breccias. These are centred on Bukit Guntung and partly overlap onto the Mangani Graben (Fig. 9) The tuffs are very pale and light in weight, containing pumice fragments, quartz, apatite and biotite phenocrysts, and occasional clasts of pre-Tertiary slate carried up by the lava. Apatite crystals can characteristically be found in pan concentrates below outcrops of the Guntung Volcanics. These are assumed to be the youngest rocks in the area, as they are the only rocks whose distribution appears to be unrelated to the faulting in the area, though aerial photograph lineaments suggest that they are still affected by minor faulting.

2.4 Hydrothermal alteration

Over large parts of the area the rocks are hydrothermally altered, with feldspars replaced by micas (sericite and kaolin), and carbonates, and patches of the finer grained rocks replaced by carbonates and quartz. Such alteration is usually most intense in the finer grained tuffs. In addition rocks are often intensively pyritised. Sedimentary rocks also show signs of hydrothermal alteration, quartzites are silicified, as well as showing pressure solution contacts between grains, and sometimes contain pyrite. Carbonaceous and calcareous mudstones from the Telisa Formation are bleached, and in some cases silicified and kaolinised.

Plate 10

0.82mm

Quartz

Carbonate

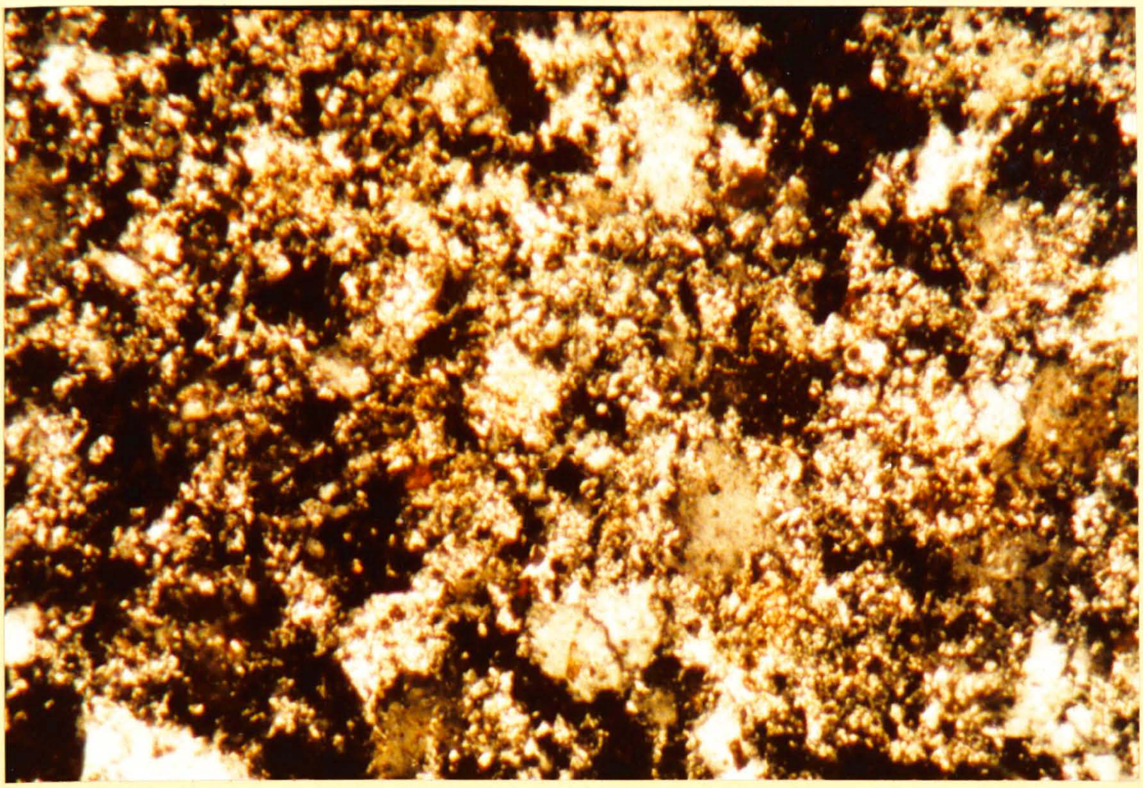
Ma R791B, XPL

0

10a/ Quartz replacing tuffaceous material, and being replaced by carbonate.

0 25cm

10b/ Kaolin zone in the S. Jeanne, unassociated with any known mineralisation.



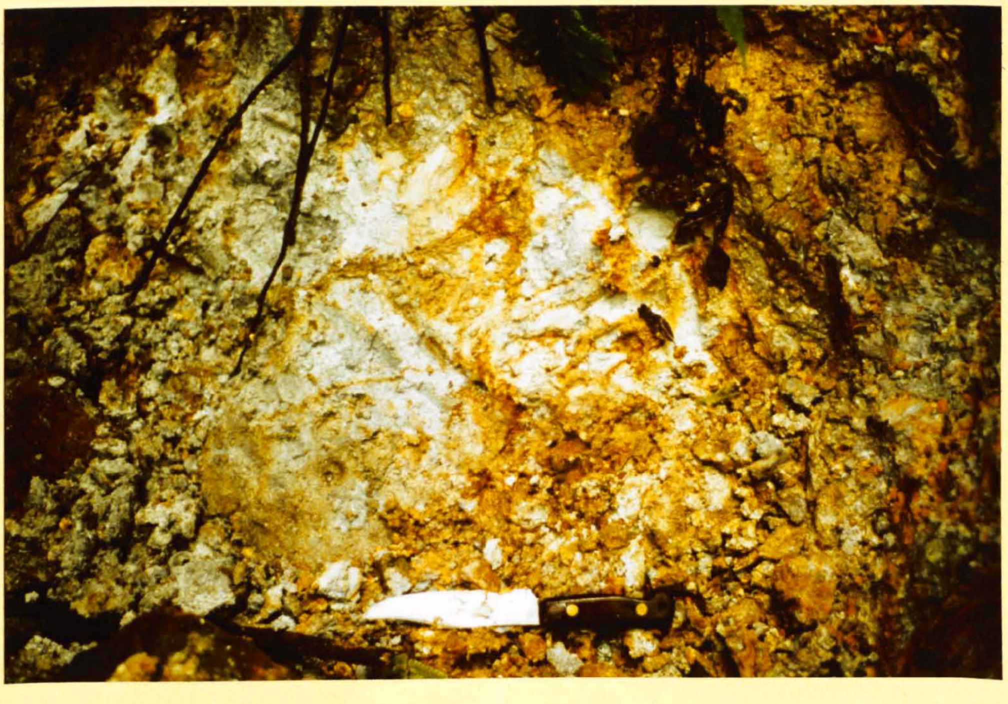
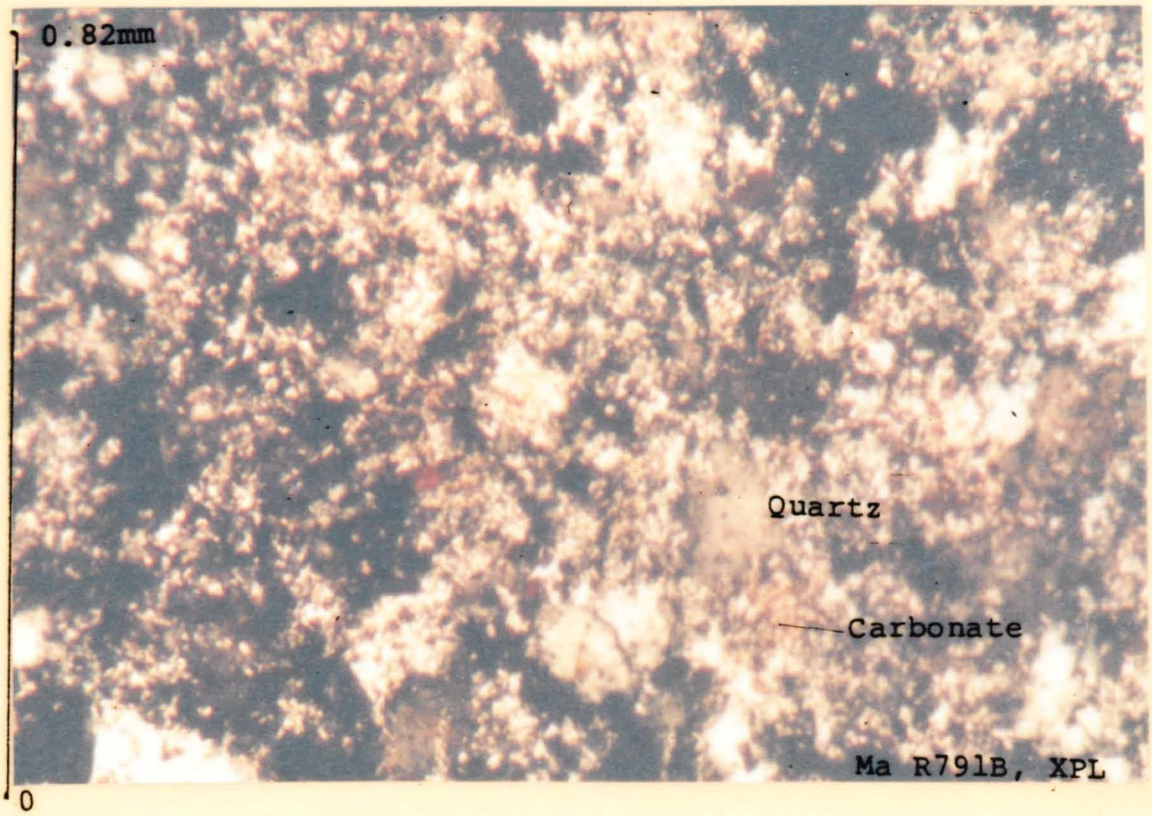
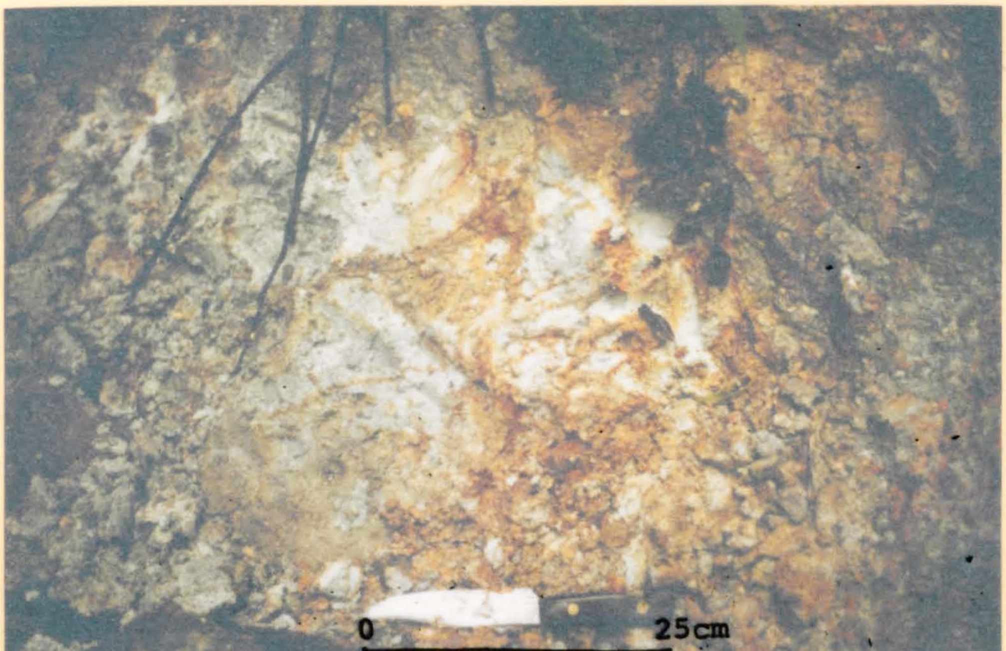


Plate 10



10a/ Quartz replacing tuffaceous material, and being replaced by carbonate.



10b/ Kaolin zone in the S. Jeanne, unassociated with any known mineralisation.

Examination of thin sections has shown, from the replacement of one set of minerals by another, that the following sequence of metasomatic alteration occurs. This alteration sequence is not universal, as often only one of the many different alteration reactions has occurred.

a/ Early replacement of the matrix of the tuffs by patches of quartz.

b/ Replacement of early quartz by calcite, or sometimes by dolomite (Plate 10a).

c/ Replacement of carbonate by later quartz.

d/ Post-alteration quartz veinlets cut many of the rocks.

In some samples pyrite can be seen overgrowing carbonates, though the common occurrence of pyrite in altered plagioclase crystals suggests that pyritisation is quite early. In other samples pyrite appears to be replaced by carbonate, and in some samples ilmenite grows along the cleavage of the carbonate.

Ferromagnesian minerals are usually replaced by chlorite, or carbonate and magnetite. In other cases secondary epidote occurs, occasionally visible in hand specimens as the pink manganese variety thulite. In some samples epidote is partly replaced by quartz.

This sequence of alteration may not be entirely due to the hydrothermal effect, as it is not known whether the volcanics were exposed to subaerial weathering before being covered by material from the next eruption. In addition all outcrops at Mangani are quite weathered, and it is not always easy to distinguish between the effect of modern weathering and earlier alteration.

In some places the extreme alteration leads to zones of kaolin along fault zones. Such zones commonly occur in the hanging wall of quartz veins, and have been explained by De Haan et al. (1933) as the result of the concentration of ground water above the impermeable quartz layer. Several highly kaolinised zones have been found apparently unconnected with mineralisation, though often the lack of exposure means that a mineralised zone could well be located nearby. Plate 10b shows an example of such a kaolinised zone.

Description of the alteration of the rocks in the Mangani mine matches the phenomena observed at the surface, suggesting that the effects seen at the surface are genuinely caused by the hydrothermal alteration, rather than by surface weathering.

2.5 Structure of the Mangani area.

2.5.1 Faulting

The structure of the area is complex, and outcrop rarely occurs outside stream courses, which almost all lie along faults. Aerial photograph analysis clearly shows the WNW trending graben, with the northern margin being marked by especially steep slopes (Figs. 6,11). At its western end the graben faults converge, and join with the main strand of the SFS (NW trending). To the east the faults diverge, and are lost under younger volcanic deposits, including the acid tuffs and breccias centred on Bukit Guntung (Plate 12). Many minor faults parallel the graben orientation.

On the aerial photographs and Landsat image a number of other lineaments are visible, some of which are marked on the overlays to Plates 1 and 2. A summary of the common lineament orientations is marked on the overlay to plate 12. The density of lineaments in the Mangani area is particularly high, and may be one of the reasons why the mineralisation occurs here. Similar factors may affect the mineralisation in the Balimbing mine (Fig. 6).

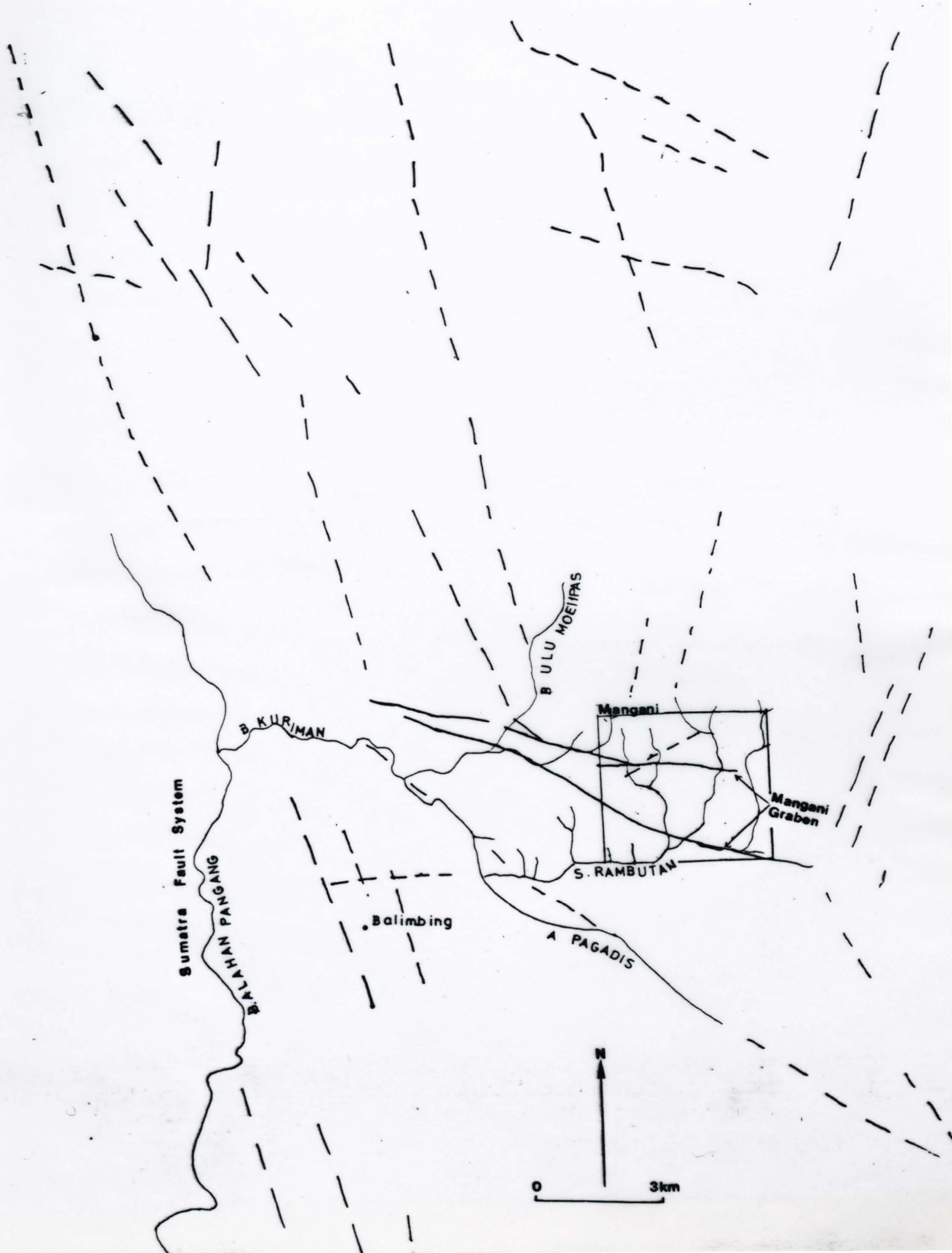
A large number of the aerial photograph lineaments could be recognised on the ground as faults, though evidence for the extent and direction of fault movement was rarely present.

Figure 12 shows a stereographic projection on the lower hemisphere of the Schmidt net, of poles to faults measured in the field. Many of the groups of fault orientations described above can be recognised, but there is quite a wide spread around these orientations.

NE-SW faults dipping at 45^{o} or more to the NW are the only faults dipping at a shallow angle which occur with any frequency.

The very high frequency of NW-SE faults recorded may partly be caused by the presence of many streams

Plate 11 Photographically enlarged Landsat image, showing the Mangani Graben, and other lineaments.



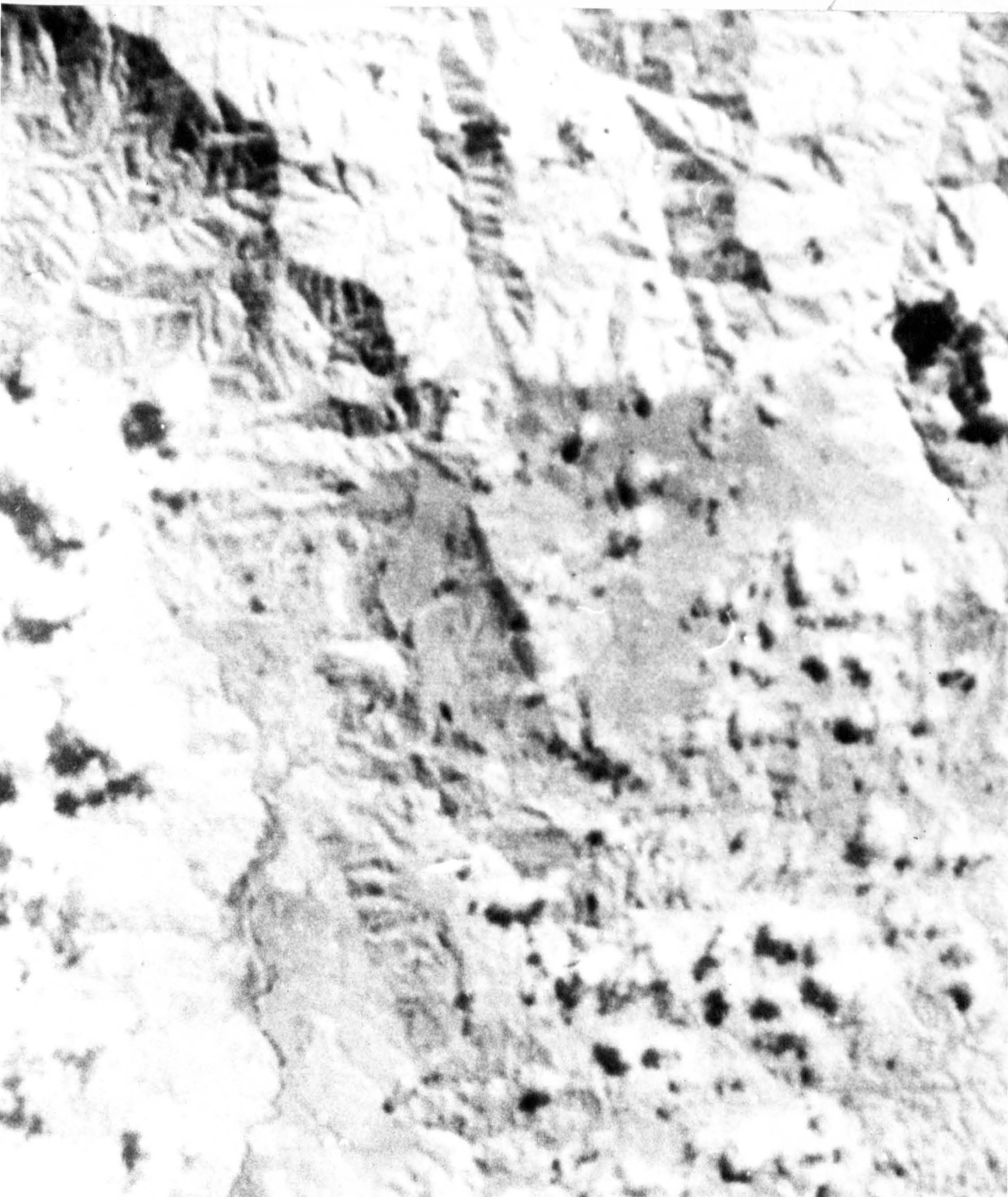


Plate 11 Photographically enlarged Landsat image, showing the Mangani Graben, and other lineaments.

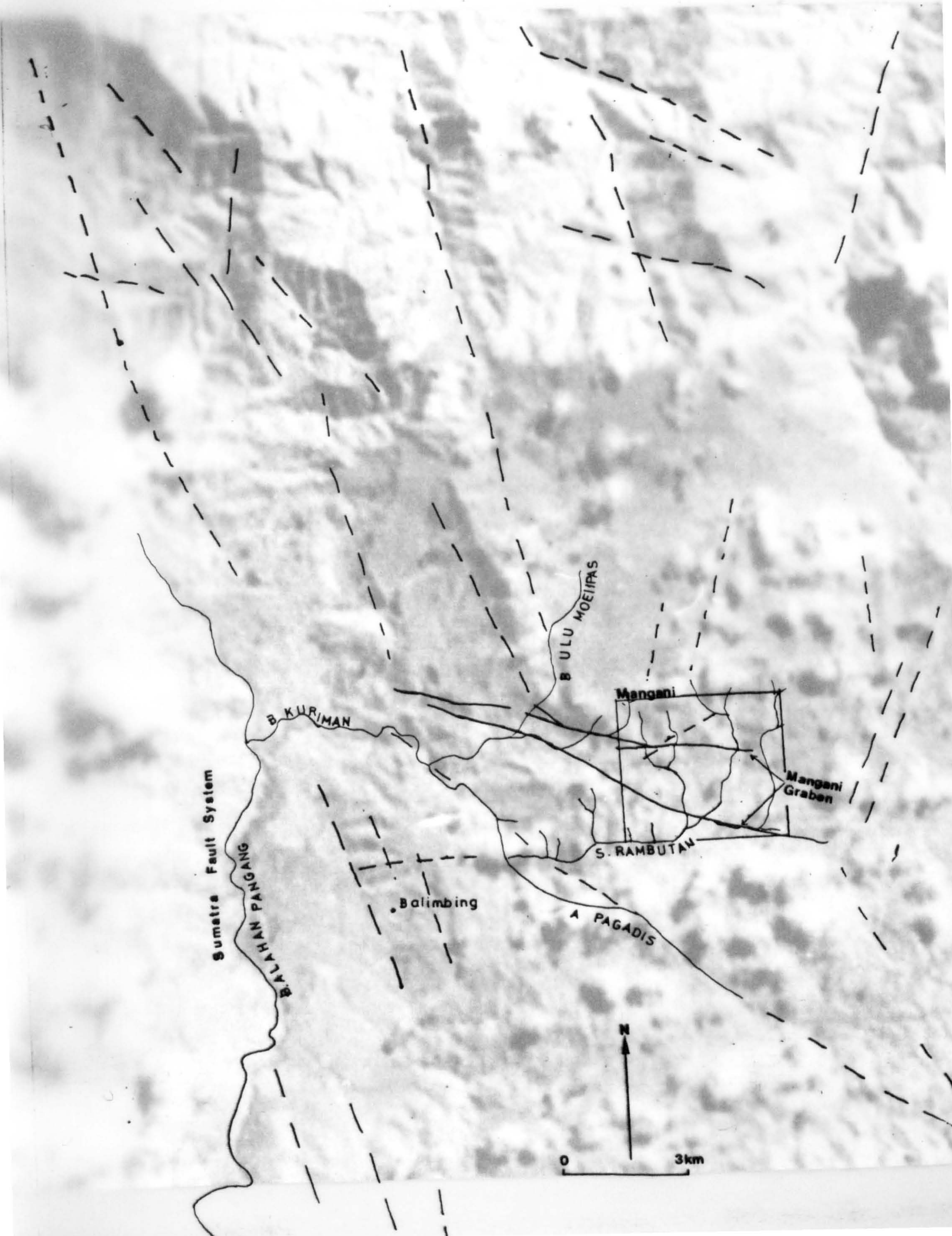


Plate 12 Enlarged aerial photograph of the Mangani area showing the Mangani Graben, and the other lineament trends in the area.

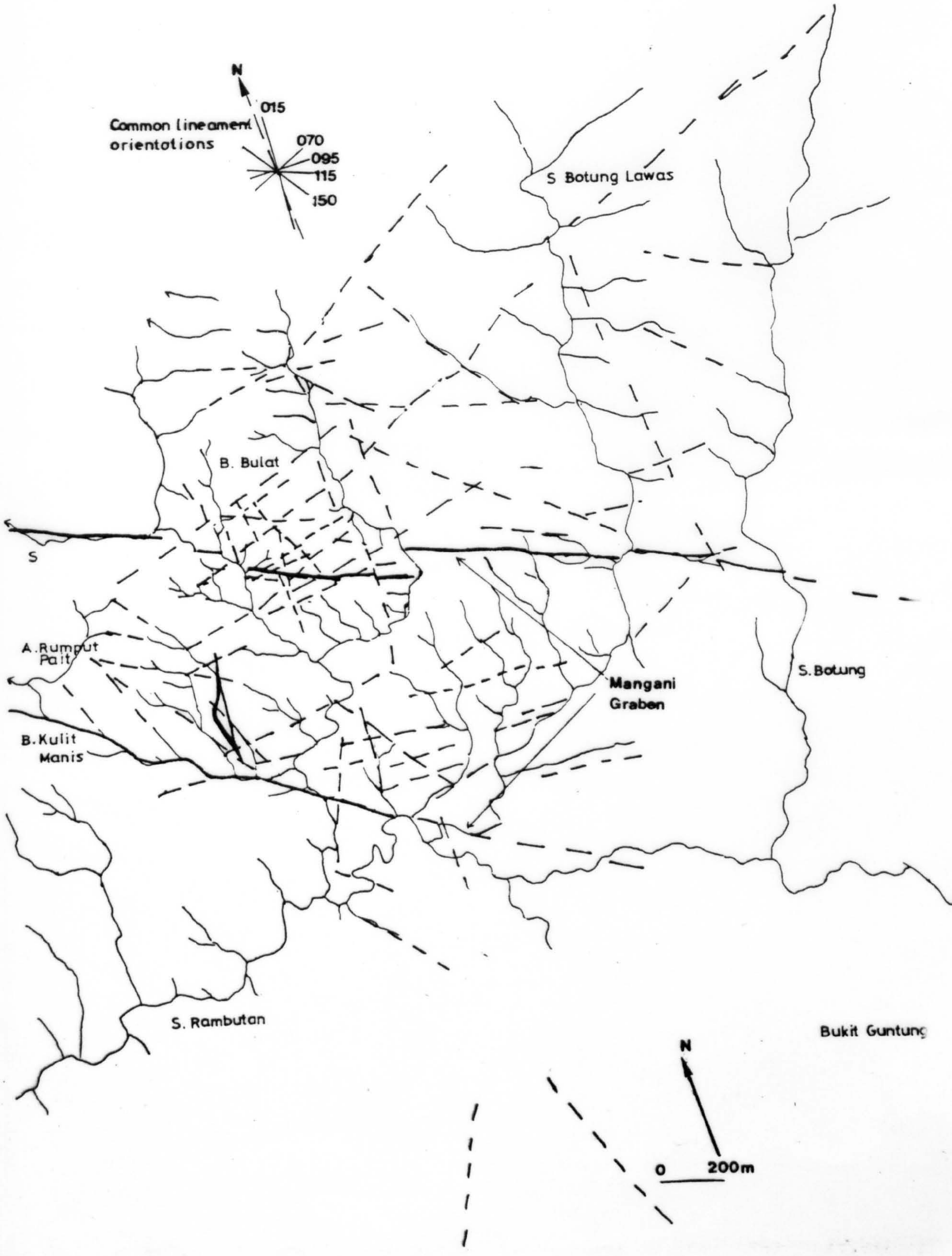
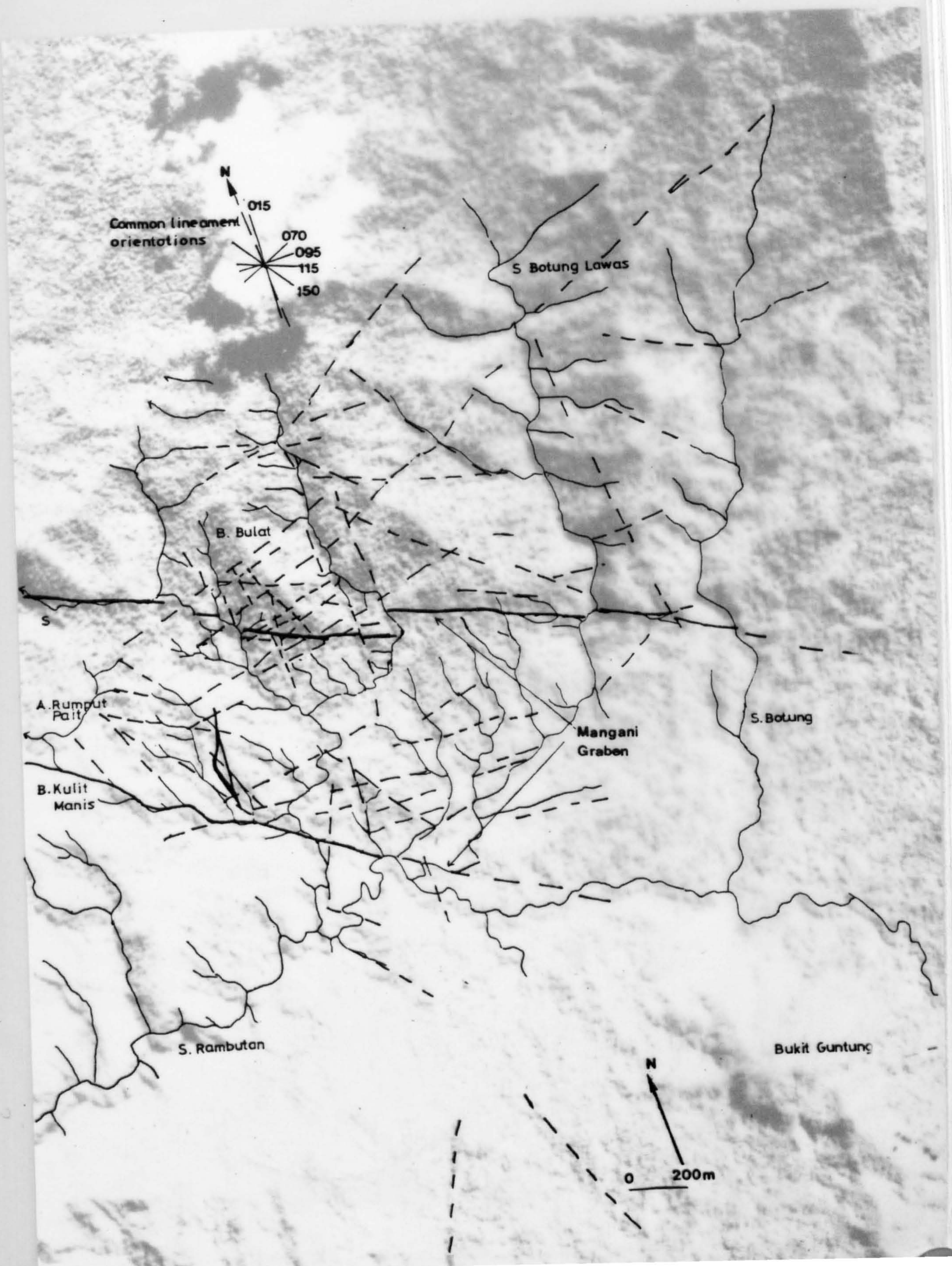


Plate 12 Enlarged aerial photograph of the Mangani area showing the Mangani Graben, and the other lineament trends in the area.



along faults with this orientation, which means that the same fault can be encountered many times on a stream traverse.

Approximately vertical faults, or faults dipping steeply in either direction, occur trending NNE-SSW and SSE-NNW.

In general more faults dip to the east than to the west.

All stereographic projections were traced from computer lineprinter plots made using a program written by R. N. Cramer (personal communication).

Many of the commonly occurring fault orientations above ground have also been reported by De Haan et al. (1933) as affecting the mineralisation in the Mangani mine.

From the degree to which one set of faults disrupts the other, the relative age of the faults are probably:-

1/ Graben faults (WNW-ESE).

Faults with this orientation can be seen in a number of places on the aerial photograph (Fig. 12), and on the ground fault surfaces and zones of brecciation with this orientation can be found. These are all marked on the geological map (Enclosure 2). The southern edge of the Mangani Graben was recognised as a fault zone by previous workers, and called the Mangani dislocation.

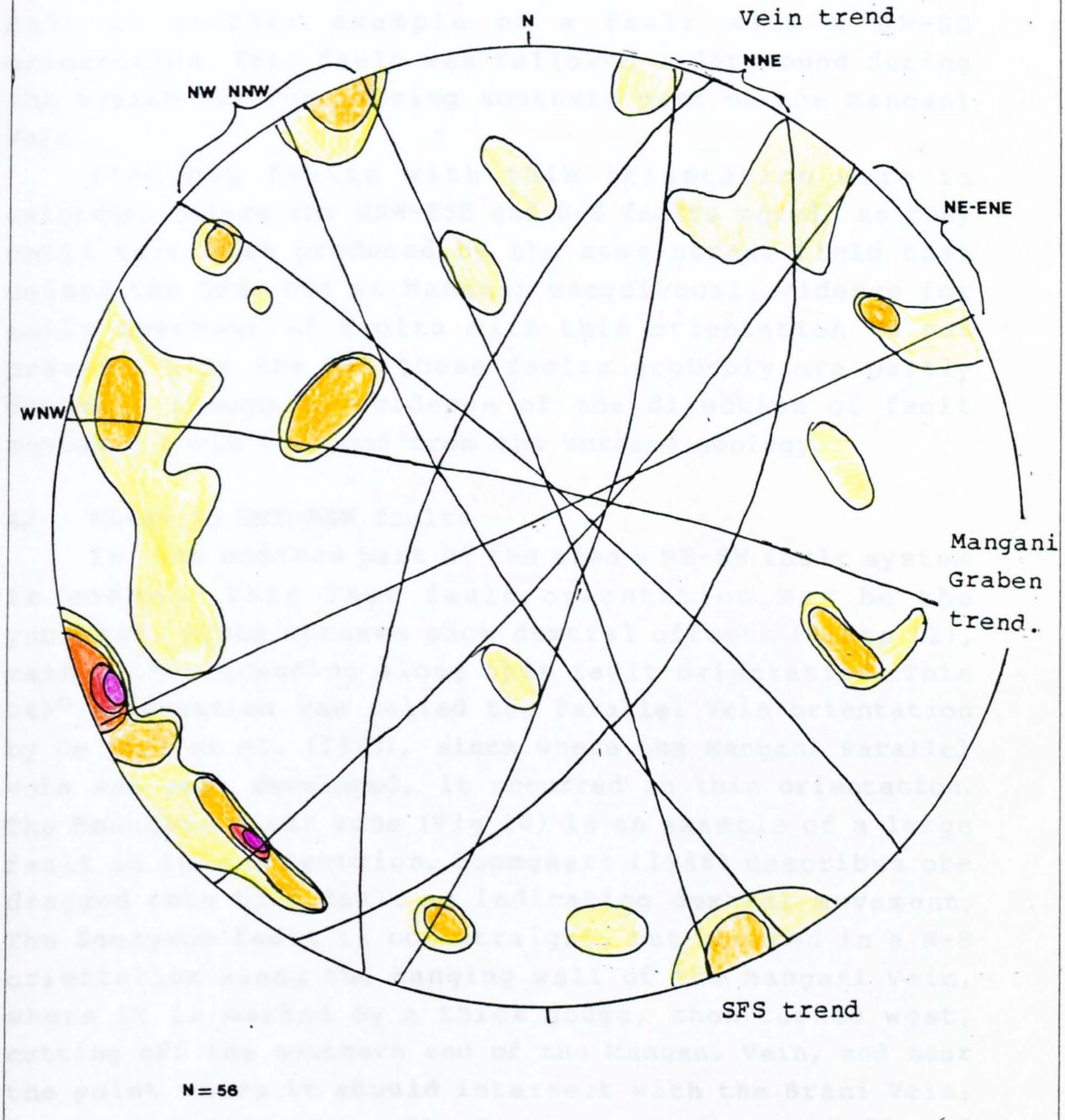
2/ N-S and NNE-SSW faults.

010 to 030 faults can be seen offsetting the northern margin of the graben. Most of the mineralisation occurs along faults of this orientation, which was called the Mangani direction by De Haan et al. (1933).

3/ Faults parallel to the Main SFS (NW-SE)

Most of the streams in the western part of the area lie along NW-SE to NNW-SSE faults, the faults being recognisable by brecciation of the rocks, and the parallelism of streams. Two main faults of this orientation are also described from within the Mangani mine as offsetting the N-S mineralisation (De Haan et al.

Figure 12 Stereographic projection of poles to faults measured in the field.



1933). These orientations are also commonly seen throughout the area as fault, joint and cleavage orientation. This 135° direction was called the Sumatra direction by workers before 1940. The Egert zone (Fig. 10, Egert I Vein shown in Figure 5) between Mangani and Rumput Pait is another example of a fault with a NW-SE orientation. This fault was followed underground during the search for the missing southern part of the Mangani Vein.

Probably faults with this orientation were in existence before the WNW-ESE and N-S faults moved, as they could have been produced by the same stress field that caused the SFS, but at Mangani unequivocal evidence for early movement of faults with this orientation is not present. Like the SFS these faults probably are partly dextral, though no evidence of the direction of fault movement could be found from the surface geology.

4/ NE-SW to ENE-WSW faults

In the eastern part of the area a NE-SW fault system is common. This last fault orientation may be the youngest, since streams show dextral offsets (Plate 12), rather than trending along this fault orientation. This 045° orientation was called the Parallel Vein orientation by De Haan et al. (1933), since where the Mangani Parallel Vein was best developed, it occurred in this orientation. The Boengsoe fault zone (Fig 10) is an example of a large fault in this orientaion. Boomgaart (1948) describes ore dragged into this fault as indicating dextral movement. The Boengsoe fault is not straight, but occurred in a N-S orientation along the hanging wall of the Mangani Vein, where it is marked by a thick gouge, then turned west, cutting off the southern end of the Mangani Vein, and near the point where it should intersect with the Brani Vein, it turns south again. The Boengsoe fault was followed underground for hundreds of metres during the search for the southern part of the Mangani Vein.

Most of the faults seen are steeply dipping, though one fault, just east of the Rambutan vein is oriented 010/30°W. This is possibly a normal fault, exposing another vein 30 m to the east which may be a hangingwall split related to the Rambutan vein. In all of Mangani there is very little evidence for the direction of fault movements, slickensides are only present in a few instances, and show oblique movements.

There is an extensive discussion in the literature of the relative ages of the Boengsoe and Egert faults and the type of movement on those faults (Boomgaart 1948, a reply to Boomgaart 1948 by De Haan, De Haan 1949b). The reason for this discussion is that the southern part of the Mangani Vein is radically cut off by a fault, and a lot of time was spent tunnelling along both the Boengsoe and Egert faults trying to find the displaced part of the Mangani Vein. A fault was also cut by the Main shaft for the Rambutan and Silver Veins in 1940, and a drift driven along it in both directions for some distance. Boomgaart considers vertical movement to have occurred simultaneously on both faults.

2.5.2 Vein and dyke orientation

Figure 13 is a stereonet plot of all mineral veins and dykes examined, as well as the orientation of some of the smaller quartz veinlets encountered. Dykes and veins occur in similar orientations, and there is no evidence that one was earlier than the other.

The single most common strike direction is N-S, or NNE-SSW, with veins dipping steeply to the east. A number of veins have a similar strike direction, but dip at a much more shallow angle (30^{o} and over). A small number of veins and dykes occur parallel to all the other fault directions mentioned previously, and in addition a number of veins strike E-W, or ESE-WNW, an orientation rarely recognised as a fault direction.

2.5.3 Jointing

The stereonet plot of the joints measured at Mangani (Figure 14), shows that the joint pattern is best decribed as extremely complex. Joints can be found trending parallel to all the fault orientations previously discussed, and with many other orientations. One result of

Figure 13 Stereographic projection of poles to veins and dykes measured in the field.

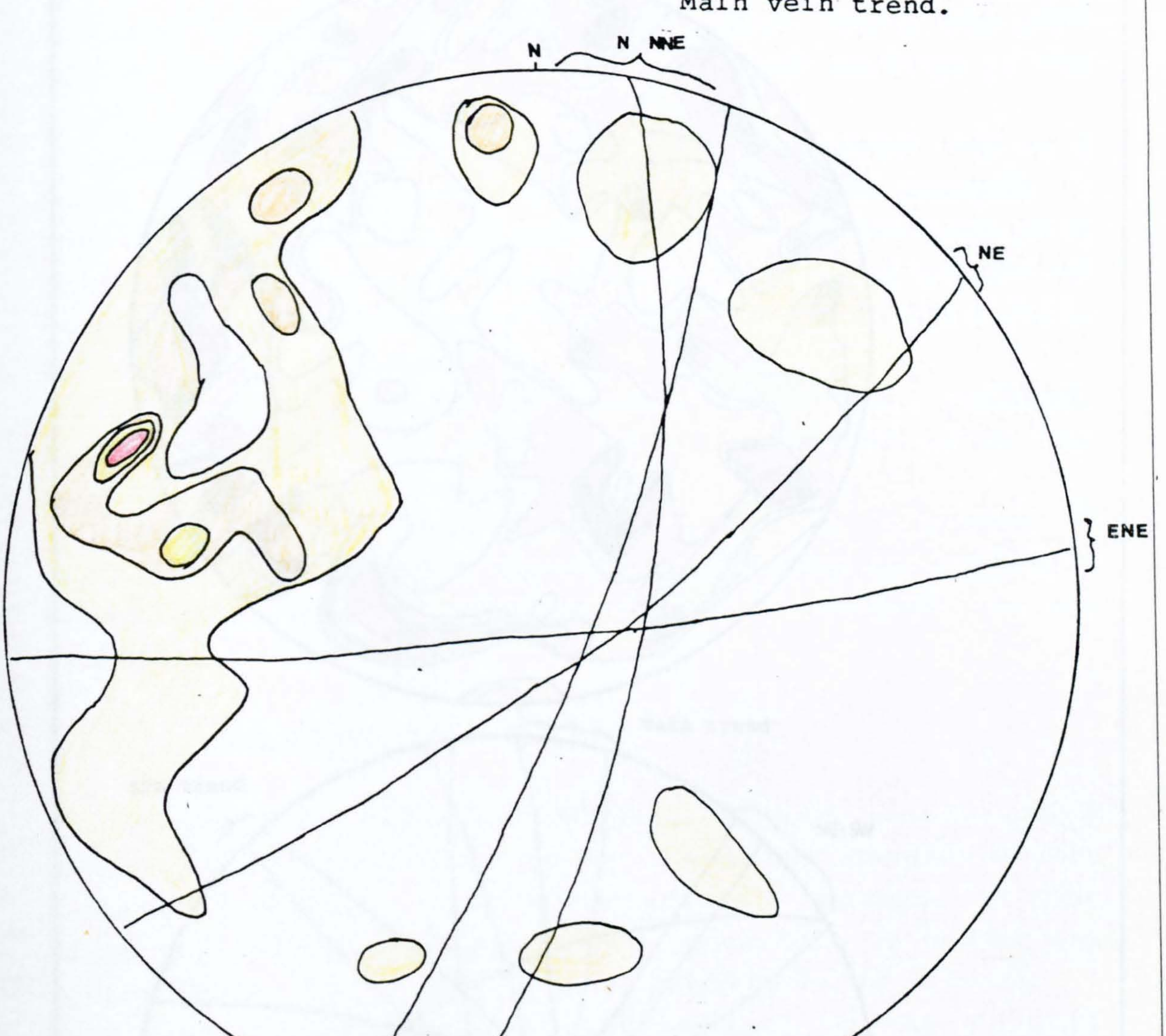
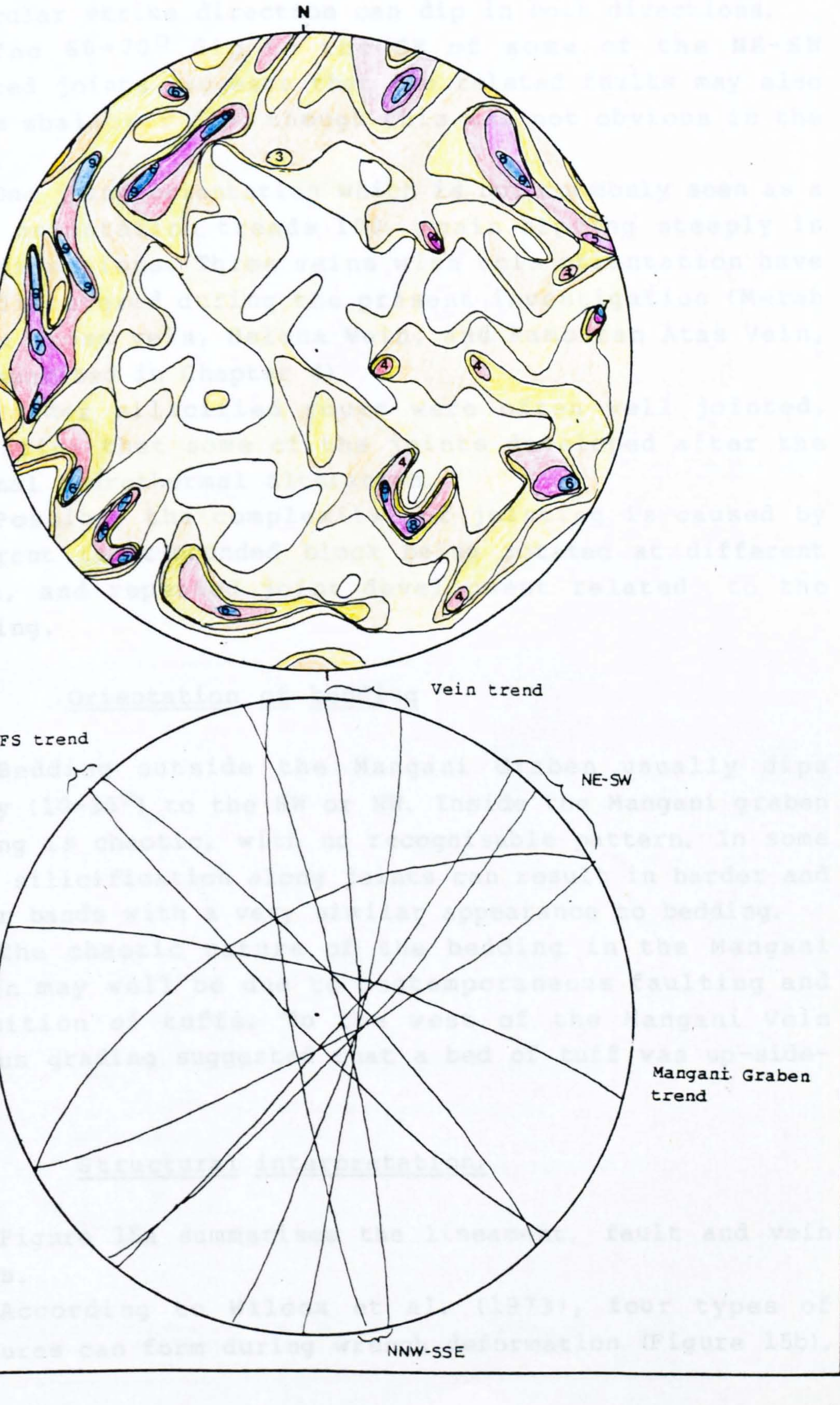


Figure 14 Stereographic projection of poles to joints measured in the field.



the poor outcrop was that faults could often only be recognised by the presence of brecciation, and many of the joints measured may in fact be faults. Generally joints dip steeply, though rarely vertically, and joints with a particular strike direction can dip in both directions.

The 60-70^{o} dip to the SE of some of the NE-SW oriented joints suggests that the related faults may also have a shallower dip, though this was not obvious in the field.

One joint orientation which is not commonly seen as a fault orientation trends 100, again dipping steeply in both directions. Three veins with this orientation have been discovered during the present investigation (Merah Selasa cross vein, Helena Vein, and Rambutan Atas Vein, all described in Chapter 4)

Harder silicified rocks were often well jointed, suggesting that some of the joints developed after the regional hydrothermal alteration.

Possibly the complexity of jointing is caused by different fault-bounded block being rotated at different times, and repeated joint development related to the faulting.

2.5.4 Orientation of bedding

Bedding outside the Mangani Graben usually dips gently (10-35^{o}) to the SW or NW. Inside the Mangani graben bedding is chaotic, with no recognisable pattern. In some cases silicification along joints can result in harder and softer bands with a very similar appearance to bedding.

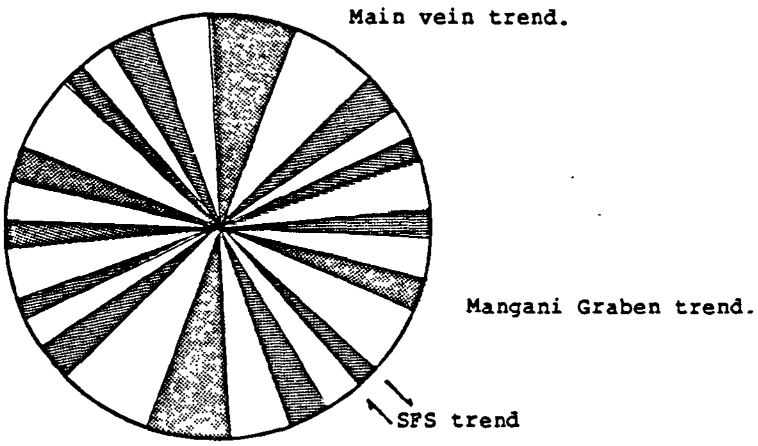
The chaotic nature of the bedding in the Mangani Graben may well be due to contemporaneous faulting and deposition of tuffs. To the west of the Mangani Vein dubious grading suggested that a bed of tuff was up-side-down.

2.5.5 Structural interpretation.

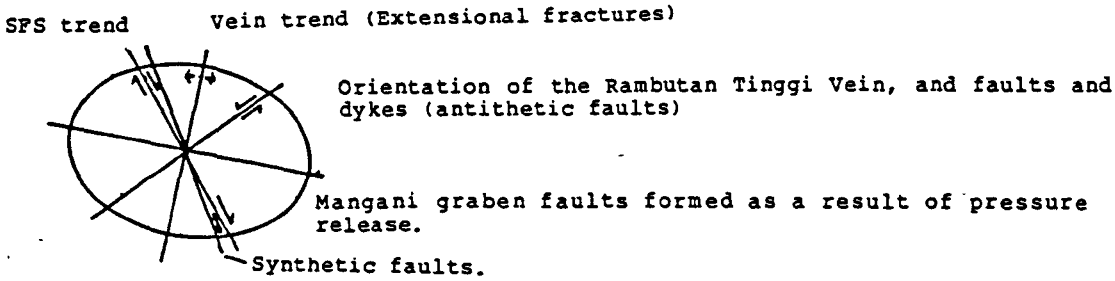
Figure 15a summarises the lineament, fault and vein trends.

According to Wilcox et al. (1973), four types of fractures can form during wrench deformation (Figure 15b).

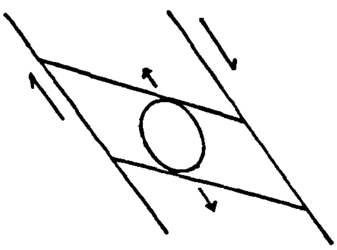
Structural interpretation of the Mangani area.



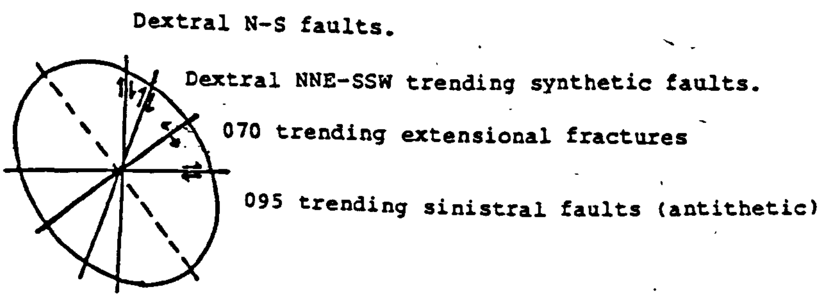
a/ Summary of fault, vein, dyke and lineament directions.



b/ Strain ellipse, showing the synthetic (dextral), antithetic (sinistral), and tensional faults expected to be related to movement on the SFS.



c/ Sketch, showing the possible occurrence of a pull apart basin between two strands of the SFS.



d/ Strain ellipse showing the fault directions expected within a pull apart basin related to the SFS.

Mangani lies only a short distance to the east of a strand of the SFS which is presently active, and it is probable that ultimately the structure at Mangani is related to the fault movement.

Faulting along the SFS will theoretically cause two sets of conjugate strike slip faults to form, with orientations of 10-30^{o} and 70-90^{o} away from the fault. The acute angle of intersection of these two fault sets is parallel to the direction of maximum compression. The fault at a low angle to the SFS should have the same direction of displacement, while the other set of faults has an opposite direction of displacement.

En echelon tensional faults will form parallel to the direction of maximum compression.

At Mangani NW-SE faults parallel to the SFS are present, and the 020 trending veins may be related to the extension direction (parallel to the direction of maximum compression), while the 055 trending veins are hosted in antithetic faults (Fig 16b).

The Mangani graben faults are considered to have formed after pressure release, so that fractures formed parallel to the direction of maximum extension. Once fractures with such an orientation had formed, they could have acted as marginal faults to a small pull-apart basin (Fig 16d). Within a pull apart basin, extension would occur parallel to the SFS, resulting in an orientation of the strain ellipse shown in Figure 16c. The other fault and vein orientations seen at Mangani can be related to this stress regime. Margins of a pull-apart basin related to the SFS could be expected to be oriented 070, but if a previously formed fracture is present, then this may be utilised. There is no simple explanation why the 115 trending faults should have been utilised to form a graben, rather than the 015 trending extensional fractures, unless these had been strengthened by the presence of quartz veins, and the 115 trending fracture was formed later.

Such a stress regime would result in dextral faulting on N-S faults, and on Plate 12, N-S dextral faults can be seen offsetting the northern edge of the Mangani Graben in the Bukit Bulat area. This suggests that the stress regime responsible for the structure of the Mangani area also operated outside the Mangani graben, and on the Landsat photograph (Plate 1), a N-S lineament appears to cause a dextral offset of the Main strand of the SFS. There is no known origin for regional faults with such an orientation.

To the east of the Bukit Bulat block, faults with sinistral displacement are present, suggesting that once these lines of weakness are present, they are utilised to resolve different stress field orientations.

This combination of fractures relating to movement on the SFS, and fractures related to extension within a local basin, could account for the relationships seen between the different fault orientations present, but the origin for the N-S faults which offset the graben, and possibly offset the SFS, cannot be determined.

CHAPTER 3

Soil and stream sediment geochemistry in the Mangani area.

3.1 Previous geochemical work in the Mangani area.

A number of government and private organisations have collected either stream sediment or soil samples from the Mangani area prior to this survey.

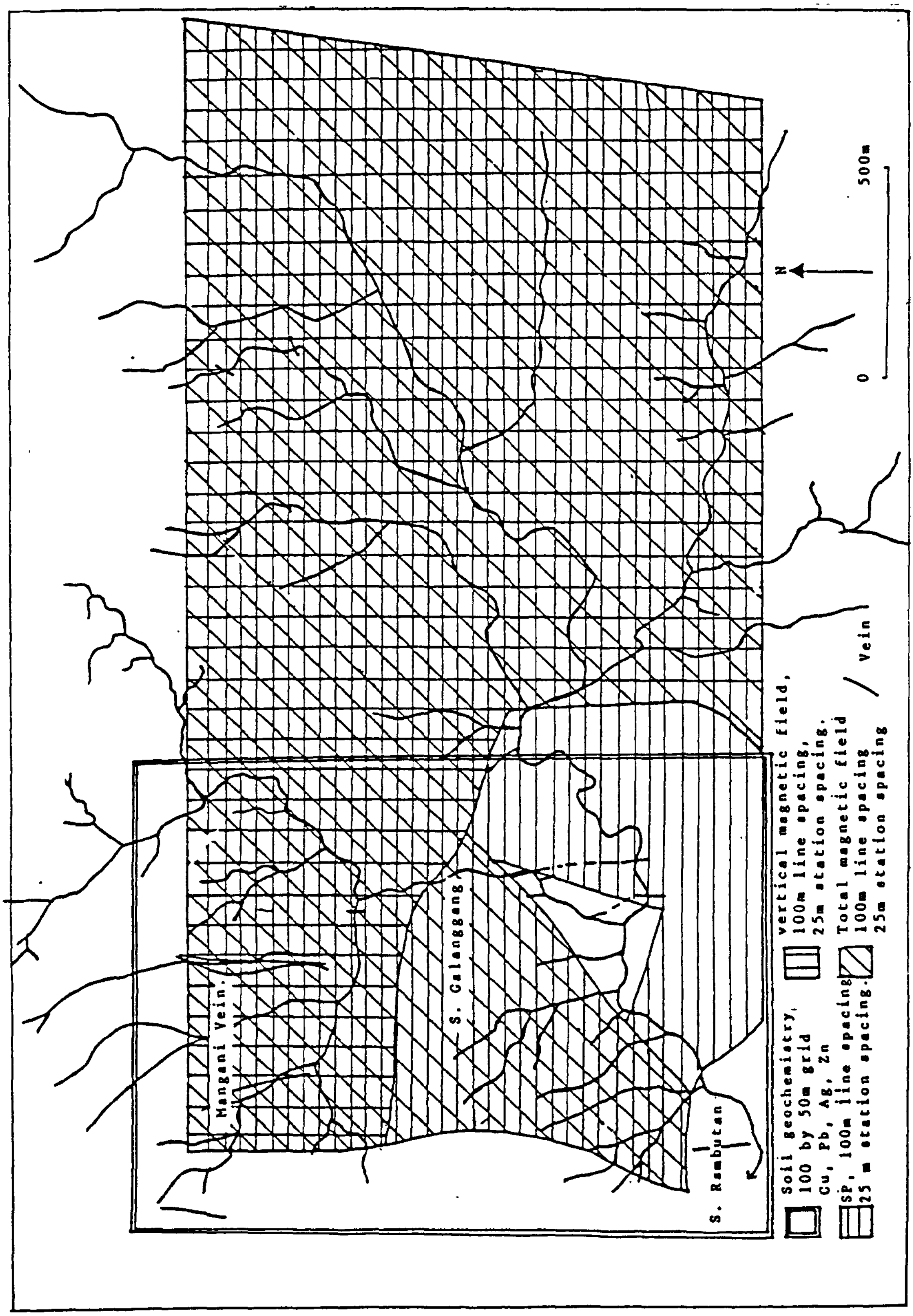
In 1974 P.T. Riotinto Bethlehem Indonesia collected a limited number of stream sediment samples, which were analysed for Pb, Cu, Zn, Mn, Ag, and As. A number of soil and rock samples were also collected, and some of these samples were analysed for gold.

The Indonesian Geological Survey (Machali et al. 1976) visited the Mangani area, and collected stream sediment samples from quite a large area, and soil samples from the southern part of the Mangani area. Stream sediment samples were analysed for Pb, Zn, and Cu. The quantities of magnetite, ilmenite, zircon, rutile and monazite in pan concentrates were also measured. Stream sediment samples from the Galanggang and Rambutan rivers were anomalous for all elements.

The soil samples were collected on a 100m by 50m grid covering many of the known veins, including the Mangani Vein. Part of this area was later investigated using geophysics by the Indonesian Geological Survey (Harsono et al. 1978). The areas covered by these geochemical and geophysical investigations are shown in Figure 16. The location of the most strongly anomalous samples is shown in Figure 17.

Stream sediment samples were also taken from the Mangani area as part of the regional North Sumatra Project investigation. Details of this work are reported in Stephenson et al. (1982). The Mangani area was conspicuous in being anomalous for elements normally associated with ultrabasic rocks (Co, Ni, Cu, and Cr), rather than the elements reported to occur in mineral veins (e.g. Ag, Au, Mn, Pb, Zn).

Figure 16 Areas previously investigated at Mangani. (Machali et al. 1976, Harsono et al. 1978)



Summary of geochemical and geophysical work by the Indonesian Geological Survey. (Machali et al., 1976; Harsono et al., 1980)

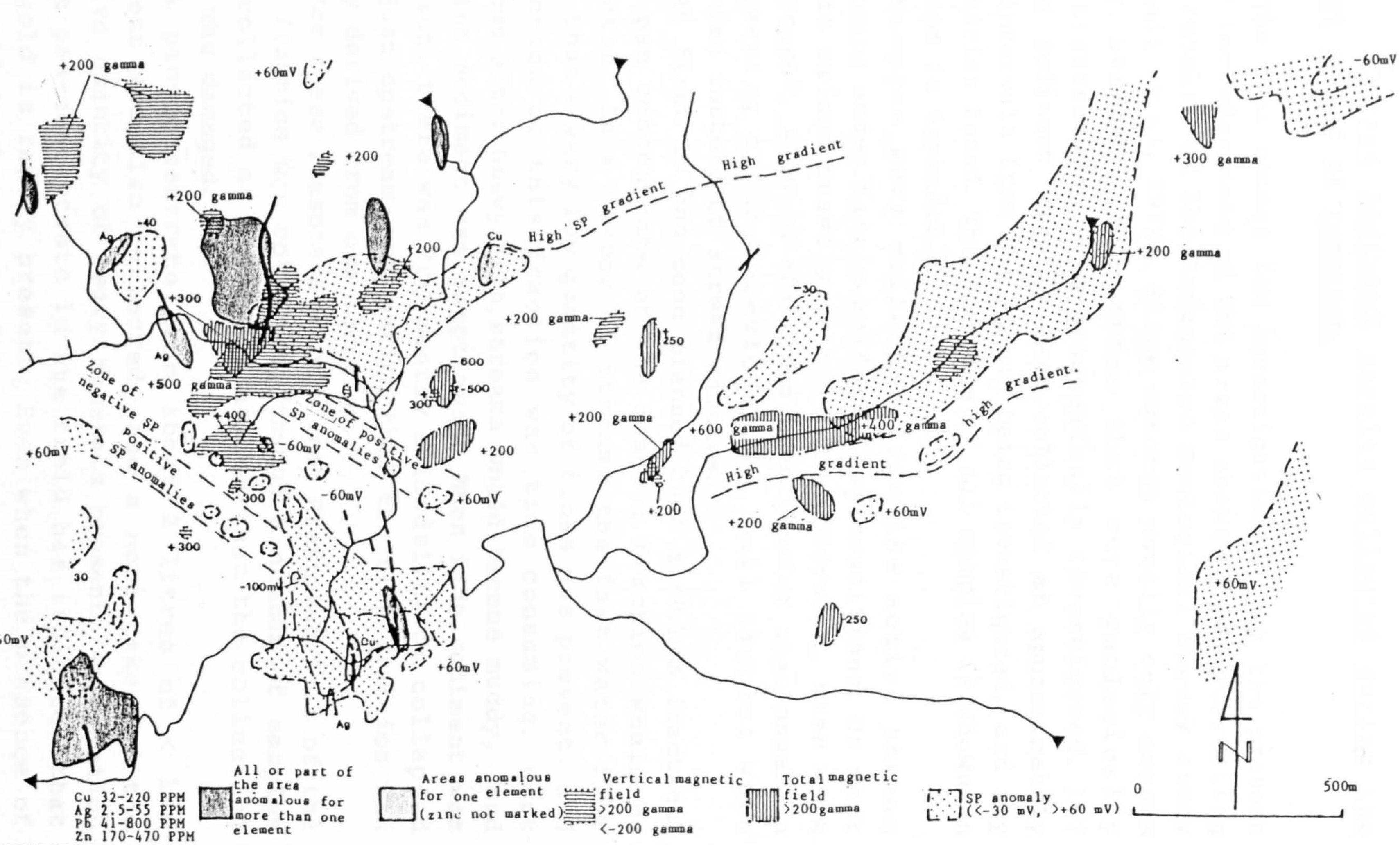


Figure 17

3.2 Introduction to the geochemical investigation.

3.2.1 Stream sediment samples collected during the present period of research.

The area chosen for investigation during the present study includes some of the areas shown to be interesting as a result of the Indonesian Geological Survey study (Machali et al. 1976). Since outcrop usually only occurs along streams, all areas that were geologically investigated were also geochemically investigated. 167 stream sediment samples were collected at approximately 150m intervals from the stream being investigated, and any tributaries found. The location of all samples is shown on the maps in Appendix B .

Samples were collected from the active stream sediments under fairly uniform flow conditions. On most days it rained heavily in the late afternoon, when work was stopped. When rainfall had been heavier than usual in the evening of the previous day, soil samples were collected instead of stream samples.

At first it had been planned that a <0.2mm fraction, and a pan concentrate of the coarser fraction would be collected. In a number of streams the fast water flow meant that a very low quantity of fines was present, and collection of this fraction was time consuming. Most evenings after heavy rain, streams would become muddy, and the fine sediment was swept away. When fine sediment was abundant, there was frequently a landslide or collapsed bank just upstream, suggesting that the fine fraction was mainly derived from one location.

For these reasons a 3 by 5 inch Kraft bag full of the < 1mm fraction was collected, though a number of samples were collected as a < 2mm fraction when the collecting sieve was damaged.

A pan-concentrate from about 2 litres of < 1mm sediment was also collected, and a note taken of the relative quantity of heavy minerals present. Examination of the pan-concentrate in the field has indicated that free gold is rarely present. Even when the presence of gold could be demonstrated by analysis, pan-concentrates contained no visible gold.

For each sample taken a note was made of stream size, rate of flow, quantity and type of precipitates, type of float, bedrock, and possible contaminants. On return to camp, the samples were allowed to dry in the sun.

On return to London tests were made on the different size fractions, to investigate the distribution of the elements within those fractions (Table II), in order to determine which size fraction should be used in the investigation of the Mangani stream sediment samples. It was found that there was very little consistency in the variation of the element content with particle size, though in general the coarser fraction of two samples from the same site showed more consistency. The variation of element content from samples from the same site seemed to be related to the quantity of fines present, which was related to the rainfall, and the time lapse since the occurrence of landslips upstream.

Table II Analytical results for pairs of samples collected on different days.

Sample	Size	Pb	Co	Cu	Zn	Ni	Mn	Cd	Ag	Au	W	Mo ppm
65	total	214	75	43	339	70	3550	2	1	<0.5	<2	0.8
	+80mesh	223	69	47	298	66	4210	4	2	<0.2		
	<80	150	82	20	359	43	2350	1	1	<0.02		
68	total	87	103	23	384	82	3290	2.5	1	<0.5	<2	0.8
	+80	120	89	32	320	69	3500	1	1			
	<80	60	95	10	120	90	1900	2	<0.5			
66	total	283	64	65	597	51	2530	5	1	<0.5	<2	1.6
	+80	300	52	60	480	44	2590	5	1			
	<80	120	90	45	452	32	2090	3	1			
67	total	266	20	32	460	24	1640	5	1	0.5	<2	1.6
	+80	292	45	42	432	45	1990	4	1			
	<80	102	12	56	250	37	1200	5	1			

Usually the quantity of fines in any one sample was small compared to the quantity of the coarser fraction, so to limit time taken up by sample preparation, the total sample was analysed. This means that when a few samples from any area contain larger amounts of fine material derived from landslips, the dispersion trains will be interrupted, but examination of field notes describing the sample appearance, has shown that samples with a large amount of fines generally have similar analytical results to adjacent samples .

3.2.2 Soil samples.

During the first field work period in Mangani 214 soil samples were collected from ridges and spurs at approximately 100m intervals. The location of all samples is shown on the maps in Appendix B. Samples were collected from the C soil horizon using a soil auger, and a note taken of soil appearance, colour, sample depth, hill slope, unusual vegetation types and drainage state of the ground. About half a 3 by 5 inch Kraft bag was filled with soil, and the sample dried in the sun at the camp. Distances between samples were measured by pacing, and a note made of the compass bearing. A number of samples were also collected from the base of slopes adjacent to streams, but took too much time to collect, since after the wettest days the soil became very plastic, squeezing back into the auger hole just made. Such samples would also contain a higher proportion of remobilised material.

Soil profiles generally consisted of a very thin (5cm) darker humus rich A horizon, then a thick yellow smooth lateritic clay B horizon. The start of the C horizon was marked by the presence of small weathered rock fragments in the soil. Landslips showed that usually the depth to more coherent bedrock did not exceed 5m. The abundance of landslips, as well as the presence of multiple soil horizons suggested that mechanically transported soils may be quite common, landslipping being the main erosion mechanism.

Samples were collected from ridges and spurs because these were not as steep as hill slopes, which frequently exceeded 30^{o}. It is hoped that soils from the ridges are not transported far. Another reason for sampling soils along the ridges was the lack of good topographic maps. Hill ridges could be seen on aerial photographs, so the sample location was more accurately known, and because of their more reasonable slope often had paths along them.

3.2.3 Analytical methods.

Most of the stream sediment and soil samples were split, and analysed by myself in London, as well as by the Indonesian Geological survey in Bandung, so that most samples were analysed in duplicate. A brief description of the analytical methods and standards of precision at Bandung is given in Stephenson et al. (1982). In London both soil and stream samples were analysed for Pb, Cu, Co, Zn, Ni, Mn, and Cd. Some samples were also analysed for Hg, Ag, Au and As.

a/ Sample Preparation.

Samples were air dried in the field. In Bandung samples were split, and half of the sample sent to London, where samples were crushed to a fine powder using a tungsten carbide Tema mill.

b/ Pb, Co, Cu, Zn, Ni, Mn, and Ag.

Most of the analytical work was done using the atomic absorption spectrophotometer (AAS) method, using a Perkin-Elmer 907A.

The method used was modified after Stanton (1966). 5ml of concentrated nitric acid was added to 0.5g of sample, and heated ($\sim 80^{o}C$). Later the solution was diluted to 15ml with deionised water and heated again, before being diluted to 25ml, and analysed.

The theoretical basis for the atomic absorption method is that electromagnetic radiation of a particular wavelength will be absorbed by a particular element, the degree of absorption being dependent upon the concentration. A solution of a sample is introduced into a flame, where the elements are volatilised to become single atoms, and absorb light shining across the flame. The light passing through the flame is measured by a detector on the other side. The amount of absorption by a solution of a particular concentration is measured using standards. At low concentrations the absorption-concentration graph is linear, but at high concentrations the graph may be curved. For this reason high concentration samples are usually diluted by a known amount of fluid. In a number of cases particularly high concentrations of one element will interfere with the detection of another element.

c/ Mercury analyses.

A flameless atomic absorption method was used to analyse for mercury. The method used was developed by C. Kyriacou at Chelsea College, after a method by Hatch and Ott (1968), and after a method developed at Imperial College in 1980. Conventional flame AAS is not sensitive enough to measure mercury down to ppb level.

Concentrated nitric acid was added to the sample to produce mercuric nitrate, which then is reduced by stannous chloride to elemental mercury. The mercury is carried into a quartz absorption chamber placed in the light beam by a carefully measured nitrogen flow. Moisture from the nitrogen and mercury gases was first removed using magnesium perchlorate to avoid reduced penetration of the light beam.

d/ Arsenic analyses

Arsenic was measured using a colorimetric method (Gutzeit test). With this method the sample is fused with potassium hydroxide, then a solution made with distilled water or dilute hydrochloric acid. This reduces sulphides and oxidises organic matter to produce pentavalent arsenic, which is reduced to trivalent arsenic and then arsine gas by addition of a $KI-SnCl_2-HCl$ solution and zinc metal. The resulting arsine gas is passed through filter paper impregnated with mercuric chloride or bromide to produce a number of coloured compounds. $H(HgCl)_2As$ is yellow, $(HgCl)_3As$ is brown and Hg_3As_2 is black. The intensity of colour varies with arsenic concentration, and can be compared with standards.

e/ Gold analyses

For Au analyses the Au was taken into solution using an HBr/Br digestion, followed by solvent extraction with with 2-methyl-pentan-2-one (M.I.B.K). The resultant solution is analysed by conventional AAS.

f/ Silver analyses.

Silver analyses were made using a hot nitric acid/ mercuric nitrate digestion to avoid precipitation of the silver as a halide. Any halogens present would react with the mercuric nitrate to form a mercuric halide, while silver remained in solution as a silver nitrate.

All other analyses were made using a simple hot nitric acid digestion.

g/ Analytical accuracy.

In order to determine the analytical errors a number of samples were repeatedly analysed in each subsequent batch of samples. Blank specimens containing only reagents and no sample were also analysed in order to detect any contamination.

Precision of results varied for each element, being approximately proportional to concentration up to about 500 ppm. Above this the percentage error increased dramatically. The following are the coefficients of variation for each element. Pb 10%, Co 16%, Cu 17%, Zn 15%, Ni 21%, Mn 20%, Cd 24%. The coefficient of variation is defined as 100 times the standard deviation, divided by the mean (Rose, Hawkes and Webb 1979).

Later soil stream sediment and rock samples were analysed by CSR Ltd (Australia).

g/ Possible interference

Interference in AAS readings as a result of the presence of large concentrations of another element can result in spuriously high or low results for a number of elements. The following details are derived from Ward et al. (1969).

If large quantities of calcium (e.g. 15,000 ppm) are present then bismuth values measured can be spuriously high (e.g. 75 ppm in a sample with only 10 ppm bismuth). The precise analytical details of analyses done at commercial laboratories by C.S.R Ltd are not available, but some of the high bismuth values obtained in rock samples may be the result of a high calcite content. This factor is not considered to be important, as most of the rocks with high bismuth contents do not have a high calcite content.

Interference in the estimation of zinc is caused by several effects, including the acid concentration, and the effects of potassium, sodium and iron.

The presence of large amounts of iron and calcium can interfere with determination of nickel.

In almost all cases these problems are likely to be more important when ore samples are being analysed, as these specimens will contain the highest concentrations of interfering elements.

3.2.4 Interpretation of geochemical results.

A number of different methods are available in order to separate anomalous from background samples. The results over known mineralisation can be compared with results from new areas. The geochemical investigation by Machali et al. (1976) has shown the element concentrations present over a number of known veins, including the Mangani Vein, and gives an indication of the element concentrations expected over unknown mineralisation. This information has been taken into account when interpreting the Mangani data, though in many cases the highest values found were much higher than the values found over known mineralisation.

An alternative method is to calculate the mean and standard deviation of a sample set, and to define anomalous samples as samples containing an element concentration over the mean plus 2-3 times the standard deviation. This method was not used, except in cases where no other criteria appeared to be available.

Attempts were made to find the threshold levels between different background and anomalous populations using cumulative frequency log concentration graphs (Sinclair 1974), but ordinary histograms seemed to give a clearer indication of the threshold levels, and these are also plotted in figures 19-31 The values used for each division are shown under the histogram. The final column of the histogram contains all the values up to the maximum, but all other columns represent a constant interval.

If only one group (population) of element concentrations is present, for instance caused by the natural variation of element content in one bedrock type, then a histogram of the number of samples with a particular element concentration would show a shape of either the normal distribution, binomial distribution, log normal distribution, or some other pattern. Geological samples frequently show a log normal distribution for trace elements and a normal distribution for major elements, although there is not yet a good theoretical explanation for this (Levinson 1980).

Element concentrations found in Mangani stream sediment and soil samples were plotted on maps using circles of different size for different concentration groups (Fig. 19-31).

The element concentrations on these figures were plotted using the computer program in Appendix C.

3.2.5 Sources of error and contamination.

Despite the care taken in sampling and analysis, mistakes may have been made, so only areas with more than one sample with high element contents are regarded as interesting.

Other causes of anomalies which are not directly caused by mineralisation include the possibility of agricultural contamination (fertilisers and pesticides), though at Mangani only small areas would have been under cultivation during the life of the mine, and before 1940 the use of fertilisers by local inhabitants was limited. At Mangani false anomalies are very likely to be caused by mining contamination. Figure 18 shows the roads, areas of mining activity, processing plants in use at various times, as well as the channels and cast iron pipe lines used to collect water for hydroelectric power and the aerial cable way used to transport ore to the processing plants. Very little is left to mark the location of houses, but rusty machinery, cables and ore trucks are scattered throughout a wide area. As well as containing rusty metal and broken crockery, streams may be

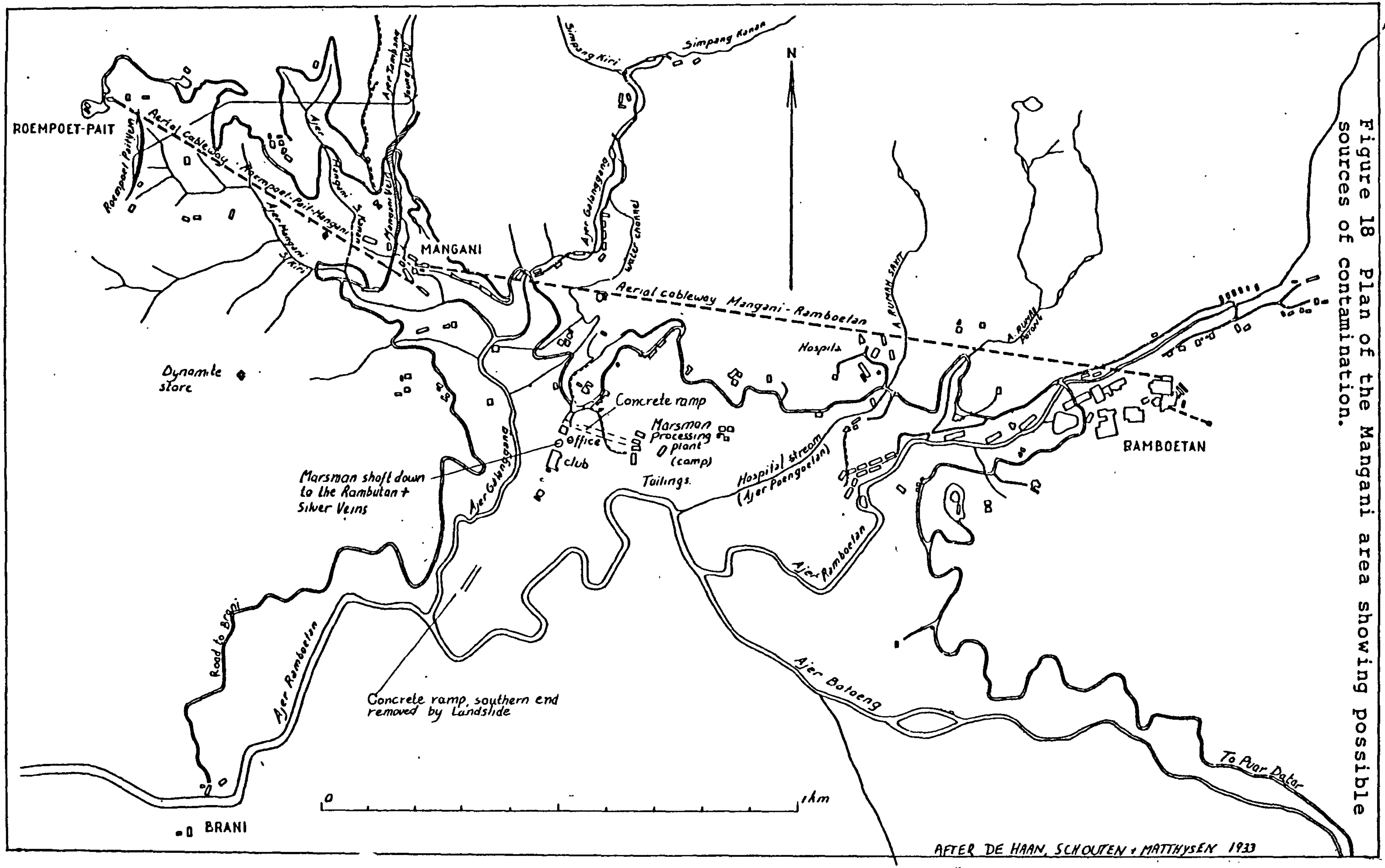


Figure 18 Plan of the Mangani area showing possible sources of contamination.

contaminated with tailings from the processing plants.

Unfortunately information about the later building work done by M.M. Marsman is scarce. The processing plant built by Marsman is shown in Figure 18, and a concrete ramp leads up the hill from this point. A shaft down to the Rambutan and Silver Veins was built on the top of the hill. The remains of jaw crushers can still be seen in this area, suggesting that some of the processing was done here. In addition a concrete ramp was found leading down from the hill to a point above the Rambutan vein, though the lower part has now been removed by a landslide. Because of the very obvious evidence of contamination in the area over the Rambutan and Silver Veins, no soil samples were collected.

3.2.6 Statistical investigation of geochemical results.

Statistics relating to the Mangani data are shown in Tables III and IV. These statistics were provided by CSR Ltd as computer output generated by a standard statistical package, so that not all of these values are directly useful in exploration geochemistry. However all of these values are included, as the extent of the variation of element concentration in the Mangani samples is well documented by these results.

The high mean values for a number of elements including Co, Zn, and Mn in stream sediment samples, and Mn and Fe in soil samples, may either be the result of a high regional background, or the result of a number of very high values. The high standard deviations for these elements indicate that the second possibility is more likely. The coefficient of variation (V) is only below 0.35 (35%) for Fe, indicating that the distribution is not normal for the other elements, and suggesting that the normal distribution does not apply to most of the elements measured in this survey.

Table III Simple statistics relating to Mangani soil and stream sediment samples.

	freq	mean	std dev	std er of mean	V	smallest val	z-score	largest val	z-score	range
Streams										
Pb	169	60	104	7.99	1.74	1	-0.56	894	8.03	893
Co	169	100	282	21.70	2.83	1	-0.35	3070	10.53	3069
Cu	169	56	97	7.45	1.73	0.5	-0.57	808	7.77	807
Zn	169	199	369	27.69	1.81	0.5	-0.55	4006	10.58	4005
Ni	169	87	157	12.10	1.80	1	-0.55	1375	8.19	1374
Mn	169	2370	7860	604.59	3.32	26	-0.30	99999	12.42	99973
Cd	151	2.1	1.5	0.12	0.70	0.1	-1.37	11	6.08	10.9
Ag	166	2.4	4.4	0.34	1.80	0.15	-0.52	41	8.87	41.25
Au	165	0.42	0.47	0.03	0.95	0.1	-0.81	3.14	6.67	3.04
W	146	1				1		2		
Mo	100	0.7	0.7	0.07	0.95	0.25	-0.7	3.2	3.5	2.95
Soils										
Pb	216	42	145	9.88	3.44	0.5	-0.29	2000	13.48	1999.5
Co	218	30	63	4.25	2.07	2	-0.45	707	10.78	705
Cu	218	25	35	2.38	1.41	1	-0.68	450	12.11	449
Zn	217	45	59	4.07	1.35	1	-0.73	450	6.77	449
Ni	218	30	40	2.75	1.37	1	-0.71	275	6.05	274
Mn	207	623	2962	5.85	4.75	1	-0.21	41900	13.94	41899
Hg	108	126	103	9.89	0.81	1	-1.22	709	5.67	708
Cd	205	5	10	0.70	1.83	0.25	-0.52	96	9.03	95.75
Ag	197	0.6	1.0	0.07	1.86	0.1	-0.44	12.5	11.50	12.4
Au	209	0.42	0.27	0.02	0.64	0.13	-1.07	1.54	4.22	1.41
As	190	3.8	5.6	0.41	1.47	0.25	-0.64	30	4.66	29.75
Li	205	17	8	0.54	0.45	4	-1.71	54	4.72	50
Cr	205	65	52	3.65	0.81	10	-1.05	290	4.31	280
Fe	205	37830	10613	841.25	0.28	3100	-3.27	72000	3.22	68900

The following definitions are derived from Gregory (1973):-

The mean is the total value divided by the number of samples, and is the value in the centre if the samples are normally distributed.

The standard deviation is the average amount by which samples vary from the mean.

The standard error of the mean is defined as the standard deviation divided by the square root of the number of samples. This value is used to estimate how far the mean of the total population could be expected to differ from the mean of the population measured. There is a 95% probability that the mean of the total population will lie within the sample mean $\pm$ 2 times the standard error of the mean.

V is the coefficient of variation, which is defined as the standard deviation divided by the mean. Sometimes this is multiplied by 100 and expressed as a percentage. This value is useful in indicating the relative, rather than the absolute variation.

The z-score indicates how many standard deviations the maximum and minimum values are away from the mean. Normally 95% of the samples lie within $\pm$ 2 standard deviations of the mean, and anomalous samples are sometimes defined as values greater than the mean plus two standard deviations. Expressing values as standard deviation units away from the mean also enables the population curve to be compared with a standard normal distribution with a mean of 0, and a standard deviation of 1. However it is obvious that Mangani data is not normally distributed.

Table IV and V show the correlation coefficients for Mangani stream sediment and soil samples between each of the elements analysed. The correlation coefficient is defined as:-

$$r = 1/n \times \sum (x-\bar{x})(y-\bar{y}) / \sigma x . \sigma y$$

(Gregory, 1973)

The correlation coefficient can vary between +1 and -1, the first indicating a perfect positive correlation, the

Table IV Correlation matrix, Mangani stream sediments.

	Pb	Co	Cu	Zn	Ni	Mn	Cd	Ag	Au	W	Mo
Pb	1.0										
Co	0.106	1.0									
Cu	-0.040	0.465	1.0								
Zn	0.897	0.100	-0.032	1.0							
Ni	0.055	0.680	0.855	0.062	1.0						
Mn	0.077	-0.007	0.051	0.010	-0.052	1.0					
Cd	0.628	-0.006	-0.049	0.648	0.007	-0.003	1.0				
Ag	-0.156	-0.042	-0.026	-0.166	-0.070	0.190	-0.209	1.0			
Au	-0.187	0.091	-0.024	-0.208	-0.020	0.199	-0.191	0.268	1.0		
W	0.059	-0.018	0.073	-0.003	-0.042	0.976	0.024	0.164	0.161	1.0	
Mo	0.195	0.029	-0.196	0.126	-0.143	0.047	0.126	0.159	0.010	0.004	1.0

Table V Correlation matrix, Mangani soil samples.

	Pb	Co	Cu	Zn	Ni	Mn	Hg	Cd	Ag	Au	As	Li	Cr	Fe
Pb	1.0													
Co	0.053	1.0												
Cu	0.095	0.487	1.0											
Zn	0.532	0.90	0.326	1.0										
Ni	0.041	0.758	0.499	0.111	1.0									
Mn	0.744	0.233	0.451	0.465	0.211	1.0								
Hg	0.029	-0.131	-0.160	0.012	-0.045	-0.097	1.0							
Cd	-0.011	-0.054	0.093	0.202	-0.060	-0.031	0.585	1.0						
Ag	0.172	-0.035	-0.090	0.2-7	-0.061	0.100	0.217	0.342	1.0					
Au	0.281	0.105	0.065	0.108	0.086	0.232	-0.069	-0.199	-0.064	1.0				
As	-0.029	-0.140	-0.015	-0.048	-0.080	-0.042	0.171	0.315	0.061	0.030	1.0			
Li	-0.004	0.194	0.404	0.116	0.194	0.167	-0.027	-0.031	-0.102	-0.130	-0.041	1.0		
Cr	-0.105	0.133	0.158	-0.024	0.145	-0.115	0.025	-0.022	-0.039	-0.092	-0.041	0.249	1.0	
Fe	0.065	0.018	0.154	0.071	0.042	0.128	0.152	0.144	0.167	0.150	0.053	-0.095	0.162	1.0

second indicating a perfect negative correlation. A value of 0 indicates that there is no correlation. The value above which a correlation is significant is partly governed by the number of samples used to calculate the correlation coefficient, and can be calculated using Student's t distribution, where

$$t = \sqrt{(n-2)} / \sqrt{(1-r^2}$$

(n = number of samples, and the number of degrees of freedom = n-2). When compared with the standard Student's t graph, the level of significance can be found. The number of samples used to produce the correlation coefficient in this case was 78 soil samples, and 93 steam samples, as the remaining samples were not analysed for all the elements. With such a number of samples, results are statistically significant at a 0.1% level where the correlation coefficient is 0.4 or over. This means that there is only a 0.1% probability that there is not a significant correlation between samples. At a 5% level, a correlation coefficient of 0.2 or over is significant. In the following discussion r=0.4 has been used as the limiting value, giving a 0.1% probability that the correlation is not valid.

Table IV shows that lead and zinc concentrations in stream sediment samples show a very high correlation (r=0.8970), and the lead content is also well correlated with the cadmium content (r=0.628). Not surprisingly, zinc also shows a high correlation with cadmium (r=0.648). Copper, cobalt and nickel have quite high correlation coefficients with each other, an association often seen related to basic rocks. Manganese is not highly correlated with any of the elements, except tungsten, where the correlation coefficient is artificially high because the low values of this element present in these samples. This suggests that complexing between Mn oxides and the other elements is not important (discussed in section 3.5).

Table V shows the correlation matrix for the soil samples, and here it is even more noticeable than for the stream sediment samples that most elements are not highly correlated. Lead, zinc and manganese all have moderately high degrees of correlation with each other. Cobalt, copper and nickel again show a moderate degree of correlation with each other, but copper is also correlated with manganese and lithium, and has a non-significant, but quite high correlation with Zn (r=0.326). Iron is not significantly correlated with any of the other elements. Except for those elements already mentioned, manganese is not significantly correlated with the other elements. Again this suggests that elements have not been adsorbed onto Fe-Mn oxides, and that false anomalies for the other elements produced as a result of scavenging are not common (discussed further in section 3.5). Cr shows no statistically significant correlations with any of the other elements. The highest correlation coefficient of any element with arsenic is 0.315 (with Cd).

Generally the precious metals show no significant correlation with any of the other elements. In stream sediment samples, silver is almost completely uncorrelated with all other elements, the largest correlation coefficient (0.190) being with manganese. Gold has a similar correlation coefficient with manganese (0.199), and silver (0.268). In soil samples, silver and cadmium show the highest correlation coefficients (0.342), with a lower correlation between silver and mercury (0.217). Correlations between gold and the other elements all have a low level of significance, the highest correlation coefficient being between gold and lead (0.281), and gold and manganese (0.232).

The correlations discussed above suggest that none of the other elements give a good guide to the presence of gold or silver, but that Pb-Zn, and to some extent Mn show some correlation, and this association is considered to be related to mineralisation. Cu-Co and Ni show quite a high degree of correlation both in soil and stream sediment samples, but are not related to Pb and Zn, and may be related to basic rocks.

3.3 Geochemical results: stream samples.

3.3.1 Stream sediment samples: Pb

Stream sediment samples showed the clearest element distribution for lead (Fig 19a). The two lowest populations form two clearly separate groups, containing between 40 and 70 ppm. Samples containing 150-352 ppm are almost exclusively located in rivers draining the Bukit Bulat area. Lead concentrations of 70-150 ppm also occur in the western branch of the Hospital stream, suggesting that mineralisation in the Bukit Bulat area may extend further east. In the SW part of the area the low lead concentrations ae possibly due to the presence of the Guntung Volcanics (Quaternary acid tuffs and breccias), though in one place galena veinlets were found in this rock type. Another area with very low lead abundances occurs in the Mangani river systems upstream of the Mangani Vein. The southern part of the Rumput Pait Vein, which is located at the top of the Mangani river system, is known to contain few base metal sulphides. The Main Rambutan river seems to contain 40-70 ppm lead, this possibly being derived from blocks of vein material which are thought to have come from the Rambutan Tinggi Vein. These blocks can be found along most of the upper reaches of this river, and often contain some galena. The single high lead value seen in the south of the area has no known cause. This sample is also high for many of the other elements, suggesting that the high values are unlikely to be due to analytical error. No areas of mining or habitation are known for that river system, though the Pagadis mineralisation occurs on the other side of G. Guntung.

Stephenson et al. (1982) suggested that high lead values are associated with mid-Permian batholiths, or are fault-related, following the main trace of the SFS. At Mangani no pre-Tertiary rocks are known, but the proximity of the SFS suggests that the anomalies may be related to that fault zone.

3.3.2 Stream sediment samples: Zn

Zinc (Fig. 19b) shows a very similar distribution to lead, with the Bukit Bulat area showing the highest values. Again the western branch of the Hospital stream shows high values. The branch of the Mangani river leading to the Rumput Pait Vein shows intermediate zinc levels (101-200 ppm), but low lead values. This may be due to the higher zinc content in the vein, but zinc is usually more soluble than lead. Alternatively these fairly high values may be associated with the Mangani volcanic series. Again the area in the SE has consistently low values (less than 60 ppm), with the same branch of the stream in the south showing a single high value (greater than 200 ppm)

Stephenson et al. (1982) found that the Mangani area had a regional anomaly for Zn (128-200 ppm), suggesting that zinc is quite mobile in this evironment.

3.3.3 Stream sediment samples: Cu

The frequency histogram in Figure 20a shows a clear division between a background population with less than 90 ppm, and a population with higher Cu values. However the spatial distribution of high Cu values does not relate to stream courses with known mineralisation, or to areas of particular lithologies. To some extent high Cu and Ni values are found in the same samples, though low and intermediate values do not show a good correlation. The correlation between high Cu and Ni values suggests that they have a common origin. If these high values are not caused by the presence of basic rocks, then most of the high values could be explained by the proximity of the sample to known mineralisation.

Samples with high values with no known cause occur in the S. Rumah Sakit to the north of the Rumah Sakit (Hospital) Vein, and also in the western branch of the S. Botung Lawas. This last area was not investigated in detail as it was too far outside the main area of interest, and ccess was difficult. One possibility for the high Hospital stream values is that the mineralisation in the Bukit Bulat area (described in Chapter 4 and 5) extends to the east, to the area to the north of the Hospital stream.

Stephenson et al. (1982) reported that copper had a well defined regional dispersion trend, with values of 30-90 ppm related to the Cretaceous Woyla group, possibly associated with lenses of serpentinite intruded along faults. It is possible, as discussed later, that serpentinite lenses are present at Mangani. Values of 9-30 ppm appear to be related to the Tertiary II sediments (e.g Telisa Formation). Quaternary and young Tertiary volcanics contain low copper values. Slightly under half of the samples contained over 30 ppm Cu, suggesting that if, as expected most of the underlying rocks are Tertiary sediments and young Tertiary volcanics, then these values are related to mineralisation rather than lithology.

3.3.4 Stream sediment samples: Mn

Manganese is another element with a clear distribution pattern (Fig 20b). Almost all samples in the Bukit Bulat area, Rumput Pait area and Mangani Vein area contain more than 2000 ppm manganese, the sediments from the Mangani vein area, as well as two samples slightly upstream containing over 4000 ppm. Again the SE part of the area has the lowest values, containing less than 1000 ppm. Samples below the Rambutan Tinggi, Hospital and Rambutan Veins have distinctly lower Mn values than samples from the Mangani Vein area. This may be due to these veins not having been worked, but may also be due to a different composition of these veins. Even in the field the high manganese content of the Mangani Vein can be seen, samples of the vein consisting of quartz and black manganese oxides, or of rhodochrosite and rhodonite. In addition the A. Tambang (Mangani Mine stream) stream bed consists of a concrete-like substance, gravel being cemented by black manganese oxides. This can easily be seen as the stream now runs down the mine, instead of along its course.

3.3.5 Stream sediment samples: Ni

High Ni values could either be associated with ultrabasic igneous rocks, or with base metal sulphides. Identification of areas of basic igneous rocks was felt to be important since these could be the source of the high manganese content in some of the veins. Stephenson et al. (1982) have reported a a third order anomaly in the

Mangani region (33-52 ppm), and Co and Cr contents were also anomalous. There is no direct evidence for ultrabasic rocks at Mangani, though a boulder of peridotite was found on the road into Mangani, and a red chert fragment found in the A. Rumah Sakit. This suggests that ophiolitic material may be present in the Mangani area.

At Mangani (Fig. 21a) a number of samples undoubtedly had anomalously high Ni content, with many values over 40 ppm, and the highest value being 1375 ppm.

The frequency histogram shows a complicated pattern, as does the element distribution map. Except for the high values near Bukit Guntung in the south of the area, all the other high values are restricted to the Mangani graben area, suggesting that they may be associated with basic volcanics. Alternatively these may be related to sulphide mineralisation, which is itself restricted to the graben area. Basic to intermediate volcanics occur on top of the sediments outside the graben area, but are probably not very thick. The distribution of the high Ni samples more closely matches the distribution of the Mangani Volcanic formation, with low values in the area of sediments interbedded with the volcanics. However though quite basaltic volcanics are interbedded with the Mangani Volcanics, most of the rocks are quite acid.

For these reasons no obvious relationship between Ni values and lithology type or location of known mineralisation could be identified.

3.3.6 Stream sediment samples: Co

Not unexpectedly the spatial distribution for cobalt shown in Figure 21b is similar to that of Cu and Ni, indicating that the distribution is probably not an artefact of analytical errors, and suggesting that there may be slivers of serpentinite along fault zones in the area. Stephenson et al. (1982) also report that the Mangani area is anomalous for Co, and since the distribution of Co was similar to Cr and Ni, discussed the spatial distribution of these elements together.

Like some of the other elements, high values occur in the Hospital stream to the north of the Hospital Vein, and also in the stream in the south east part of the area, on the western side of Bukit Guntung.

3.3.7 Stream sediment samples: Mo

Samples from Mangani were analysed for molybdenum as there was the possibility that the gold/silver veins at Mangani occurred above a porphyry copper deposit, in a similar way to the idealised porphyry copper deposit model described by Sillitoe (1973). Large areas of Mangani are hydrothermally altered, and pyritised, and could represent the propyllitic and phyllic alteration zones above a porphyry copper deposit. Porphyry copper deposits are often associated with high Mo values, so analysis of Mo could help prove this theory.

The Mo values at Mangani (Fig. 22a) are all low, and since high Cu values are not particularly abundant, it is unlikely that a porphyry copper deposit of any importance is present near the surface, though it is still possible that such a deposit occurs 1-2 km below the surface.

The highest molybdenum values are below some of the known veins, suggesting that Mo may be associated with the mineralisation, but since most samples were below the detection limit, and more sensitive methods are expensive, this element is not of value as an indicator of mineralisation.

3.3.8 Stream sediment samples: Cd

Not unexpectedly, the Cd content of stream sediment samples (Fig. 22b) has a similar distribution to the Zn content, though only the stream west of Bukit Bulat, and the Rambutan river have consistently high values. Again the high values in the Hospital stream occur to the north of the Hospital vein.

3.3.9 Stream sediment samples: Au

The frequency distribution histogram (Fig. 23a) shows only one population, suggesting a common origin for all the Au values.

The highest values are associated with the known mineralisation of the Rumput Pait Vein. Surprisingly samples from the A. Tambang, near the Mangani Vein have a low Au content. This may be due to the fact that the sample was collected from the dry stream bed, as the water now runs through the mine, while other samples were collected from the active sediment. Samples below both the Hospital and Helena Veins have high Au contents. Again the samples from the S. Rumah Potong to the north of the known veins have high Au values, pointing to mineralisation further to the north. The high Au values in the Botung river samples have no known origin, and are unusual in that other elements do not have elevated values in these samples. The Bukit Bulat area has moderately high values.

3.3.10 Stream sediment samples: Ag

No clear division into separate populations can be made from the frequency histogram in Figure 23b, suggesting that there is a single source for the silver in the Mangani area.

Both the Mangani and Rumput Pait Veins have particularly high Ag values in stream sediment samples below the veins (41 ppm below the Mangani Vein). The high values in these areas may be caused by the working of the veins, the same possibly being true of the Hospital Vein, which was being worked on a small scale by local people during this survey,and who used the river in all stages of their operation.

It is interesting to note that similar high values occur in the eastern branch of the S. Rumah Potong, but upstream from the known mineralisation. This suggests that more mineralisation must lie to the north.

The Bukit Bulat area has moderately high values, though the most westerly stream of the A. Galanggang has the highest values, a pattern not matched by the Pb and Zn values.

The moderate values in the Rambutan river may be derived from the Rambutan Tinggi or Rambutan Atas Veins, though two values in the eastern branch of the upper part of the Botung Lawas river suggest that mineralisation may still occur further upstream.

Except for these last values, most high Ag values are restricted to the Mangani graben area, suggesting that the silver content may be related to the volcanics.

3.4 Geochemical results: Soil samples.

Soil samples do not show such clear element distributions as the stream sediment samples. In almost all cases base of slope samples have higher element abundances than near by samples along hill ridges. This suggests that seepage anomalies caused by the solution of elements, transport by groundwater, and redeposition, may be responsible for the higher values.

The Bukit Bulat area is again notable for high lead, zinc and manganese.

3.4.1 Soil samples: Pb

Lead values (Fig. 24a) could clearly be divided into two groups, the values below 50 ppm being almost normally distributed, with the mode at 10-20 ppm. The Indonesian Geological Survey (Machali et al. 1976) found a lead anomaly over 41 ppm over the Mangani Vein, suggesting that values over 50 ppm are likely to be related to mineralisation rather than bedrock. Despite this clear separation into a background and an anomalous population the distribution of high values outside the Bukit Bulat area does not have a clear pattern. Areas A, B and C may be of significance in that they each contain more than one sample with elevated values, and these three areas may even be part of a N-S vein. Area D appears to be elevated for a number of elements, and the map in Machali et al (1976) also shows this area as anomalous.

3.4.2 Soil samples: Zn

Zn values greater than 170 ppm were found by Machali et al. (1976) related to parts of the Mangani Vein. The results of this survey suggest that values below 40 ppm form a separate population, possibly related to bedrock type, as samples collected over the Brani conglomerate show such values (Fig. 24b). Generally only a few samples contain more than 100 ppm Zn, most of these samples being located in the Bukit Bulat area. The other high values are sporadically distributed, though generally the intermediate values are located in the Mangani Graben area.

Generally the base of slope samples have higher zinc contents than samples from adjacent ridges, suggesting that seepage anomalies are present. Areas A and B have high Zn values not related to known mineralisation. These areas are also anomalous for a number of other elements.

3.4.3 Soil samples: Mn

Unexpectedly the frequency histogram (Fig. 25a) for manganese ... not easily be divided into different populations. Except for the high values to the east of the Mangani vein, the high values are mostly located in the Bukit Bulat area. Areas A and B have moderately high values, and these areas are also anomalous for a number of other elements. Most of the soils formed over the Brani conglomerate are very low in manganese, except over the northern extension of the Brani, Rambutan and Silver Veins.

3.4.4 Soil samples: Cu

Cu values over 32 ppm occur over some of the known mineralised areas (Machali et al. 1976). The histogram for copper values in samples collected during this survey (Fig. 25b) appears to show slightly different values, in that copper values can be divided into three populations, with the background population containing less than 20 ppm, and a high population containing over 50 ppm Cu. Generally the base of slope samples contain much higher amounts of copper, suggesting that seepage anomalies may be important.

The soils over the Brani conglomerate are generally low, except in the area possibly located over the northern extension of the Brani Vein. Other anomalous hillridge samples occur near the Mangani Vein, or in the eastern part of the area, especially over the main area where the Mangani volcanics occur. The Bukit Bulat area again appears to have anomalously high copper values.

3.4.5 Soil samples: Co and Ni

Cobalt and nickel (Fig. 26b, 27), which could be expected to have a similar distribution to chromium have sporadically elevated values in the west of the area, though these elements are also higher in the Bukit Bulat area. Both cobalt and nickel seem to only show a single distribution, in contrast to chromium (see 3.4.7)

3.4.6 Soil samples: Cd

There appears to be little separation of the frequency distribution histogram (Fig. 26a) for cadmium into different groups, with a single normal population below 60 ppm, and a number of scattered high values. The distribution of Cd in soils does not appear to be very closely related to Zn, suggesting that if they were originally linked, they behave in different ways during soil formation. High Cd values appear to be unrelated to known mineralised areas, except that a number of samples which have high Hg contents, also appear to have raised Cd contents.

3.4.7 Soil samples: Cr

Unlike Co and Ni, which consist only of a single population, the histogram of the Cr content in soil samples (Fig. 28a) shows the presence of at least two distributions.

Chromium is noticably higher (greater than 120 ppm) in the SE part of the area investigated. Usually high chromium values are associated with basic rocks. In a number of streams basalt dykes have been found, and abundance of basalt float in some areas suggested that larger areas of basalt outcrop may exist. In the SW of the area a block of peridotitic material was found on the road. This may either have been locally derived, or brought in when the road was built. One of the reasons for analysing for chromium was to detect any basic and ultra-basic bodies present. However the high chromium values seem to occur in an area where the main rock type is the Mangani volcanic series. Stephenson et al. (1982) report that high Cr values are associated with lenses of serpentinite located in fault zones in other areas of Sumatra, but at Mangani the very large number of faults present meant that Cr anomalies could not be related to any particular fault zone. Cr was also not correlated with any of the other elements (Table V), so that the relationship of the chromium content to either the mineralisation, or bedrock type is unclear.

3.4.8 Soil Samples: Fe

A number of different populations can be seen in the frequency histogram (Fig. 28b), possibly being related to different lithologies. Alternatively the iron content may be related to mineralisation, or to the effects of regional pyritisation. Another possibility is that the iron content is more related to the amount of lateritisation. If base of slope samples are ignored, a number of different areas with elevated iron contents can be defined. One of these areas lies over the northern extension of the Brani Vein, another over the northern extension of the Rambutan and Silver Veins. The Bukit Bulat area again has some of the highest values. The origin for the high values to the south of the Mangani Vein is not known, though they may be related to pyritisation along the southern edge of the Mangani Graben. The stream to the east of the Mangani Vein is again associated with higher values, which may be related to the faulting along this stream, or may be a seepage anomaly. Areas A and B have elevated values for which there is no explanation.

3.4.9 Soil samples: Mo

In most samples the molybenum content is below the detection limit (1 ppm), and those samples with measurable Mo do not appear to form a coherent pattern (Fig. 29a).

3.4.10 Soil samples: Li

Samples were analysed for lithium, as pegmatites enriched in lithium may possibly be asociated with the Mangani porphyry, and in addition lithium is sometimes enriched in alteration zones (Boyle, 1979).

Like zinc, lithium values are low to the south of the Mangani graben (Fig. 29b). This suggests that both the Brani Conglomerate and its thin veneer of Amas Volcanics, and Guntung Volcanics have low Li contents. The Bukit Bulat area, as well as most of the area underlain by the Mangani Volcanic Formation have higher Li values.

The significance of the higher Li values is not entirely clear. Lithium values were generally not very high, suggesting that pegmatites were not present, though it is possible that higher lithium values are associated with altered rocks, as large areas of the Mangani Volcanic Formation have been extensively altered, and the Bukit Bulat area is also extensively mineralised. However, the lithium content of samples does not uniquely delineate areas of mineralisation, so Li is not considered to be an element useful in exploring for gold deposits in such areas.

3.4.11 Soil Samples: Hg

Not all the samples collected were analysed for mercury, but of those samples analysed, the only area in which a number of samples with high Hg values occur, is located near the northern edge of the Mangani graben (Fig. 30a), suggesting that mercury is being concentrated and moved upward along faults.

3.4.12 Soil samples: As

Unfortunately, high arsenic values appear to be almost randomly distributed, with two adjacent samples with high As contents being rare (Fig. 30b). The group of high values at C may be associated with the northern extension of the Brani Vein (marked on Fig. 5). Some of the other high values in this area may be related to the northern extension of the Rambutan and Silver Veins. The high values near the Mangani Kiri stream may be caused by contamination, as the aerial cableway carrying the ore ran above this area, and pieces of cable can still be found on the ground. However other elements do not appear to occur in higher quantities in this area. The Bukit Bulat area again has a number of elevated values. The high values in the SE of the area have no known origin.

3.4.13 Soil samples: Ag

The previous geochemical work by Machali et al. (1976) showed that some of the known mineralised areas contained soil samples with over 2.4 ppm Ag. Generally few of the samples collected during the present investigation contained such silver values, and these values showed a sporadic distribution.

The spatial distribution of Ag values (Fig. 31b) has some similarity to the distribution of As, with a group of higher values at C possibly occurring over the northern part of the Brani Vein. The Bukit Bulat area again has a number of moderately high values. Similarly a group of high values occurs to the north of the S. Rumah Potong at A. This point lies approximately over the northern edge of the Mangani graben, and has elevated values for other elements, in particular for mercury. Another area which persistently has anomalously high element concentrations occurs at B. The cause of the high values near the stream to the east of the Mangani mine stream is not known, but these may be seepage anomalies related to the Mangani mine itself.

3.4.14 Soil Samples: Au

Most samples are below the detection limit (0.5 ppm for many of the analyses), but a significant number of samples contain detectable gold, and samples containing gold appear to be scattered throughout a large area (Fig. 31a), suggesting that disseminated Carlin type gold mineralisation may occur in this area. However most gold analyses were done by the Indonesian Geological Survey, who pointed out that they were not happy with some of the results, but that all the sample had been used. Most of the samples to the east of the A. Rumah Poting with high gold values had been analysed in one batch. Some of these samples were also analysed in London, and gave similar results, suggesting that these results are valid.

Some of the samples in the SE of the area were collected near a road, and as there is a distinct possibility of contamination after 30 years of mining, and forty years of local exploitation of gold-bearing veins, it is considered that these samples are not significant. Some of the samples in the south of the area contain gold, but this may be derived from mineralisation similar to the occurrence at Pagadis (De Haan, 1948), where blocks of ore were found in these younger volcanics. The Bukit Bulat area again appears to have a number of samples with higher gold values, and another area which is frequently anomalous for different elements occurs to the east of the A. Rumah Potong. Another area which contains samples collected at different times, and analysed in different batches occurs to the south of the Mangani Vein. This area is generally not noticeably anomalous for the other elements analysed, and the origin of this anomaly is not known.

3.5 Scavenging effect of iron and manganese

At Mangani a number of veins have a high manganese content, as well as pyrite, suggesting that Mn and Fe in themselves may be good indicators of mineralisation. Unfortunately both iron and manganese are known to have a scavenging effect so that a soil or stream sediment sample with large amounts of these elements may have high amounts of other elements, even though the parent rock was not particularly enriched in those other elements. Fine colloidal material and organic matter can also behave in a similar fashion. Scavenging of heavy metals by secondary oxides can take place by any of the following mechanisms:- coprecipitation, adsorption, surface complex formation and ion exchange mechanisms (Chao and Theobald, 1976). Whitney (1975) has shown that oxide coatings are more common, and have a greater thickness on larger grains and cobbles, suggesting that the scavenging effect should be maximised in the size fraction used in this survey. However, Table IV shows that the correlation between Mn and the other elements in stream sediment samples is not significant, suggesting that Mn scavenging has not had a large effect upon the concentration of the other elements. Table V shows that there is quite a good correlation between Mn and Pb, Zn and Cu, suggesting that Mn scavenging in soils is more important, but this correlation may also be due to these elements occurring together in the mineralisation. Possibly the lack of Mn scavenging in stream sediments is due to the high flow rate of streams, and the size fraction used. After each evening's rain, the Mn coating on the sand size grains may have been removed by the turbulent action of the water. In the field it was noted that often larger boulders had a heavy Mn coating, while smaller cobbles did not.

Despite the fact that heavy metal contents may generally be enhanced by the presence of Mn and Fe oxides, the results of Carpenter et al. (1975) suggest that anomaly to background ratio for Cu and Zn can be considerably higher in oxide coatings. Pb is reported to be unaffected by the scavenging process. This suggests that high manganese content may even be of value in discriminating between anomalous and background samples.

3.6 Multiple element diagrams

A number of the elements were combined to form multi-element maps. Different elements were either added arithmetically, or multiplied by a simple factor before being added together, so that values were of a similar order. Elements combined in any group are those with a high correlation. Manipulation of computer plots showed that the method used was the most effective in outlining specific areas. Attempts were made to bring the different groups of elements into equivalence by comparing the modes, medians or means, and expressing the distribution as standard deviation units, but maps produced showed a more confusing anomaly pattern than the maps shown in Figures 32 to 37.

It is considered that the non-normal distribution, and the abundance of anomalous samples in the different populations were the cause of the lack of success of the more sophisticated approaches.

Figure 32 shows a map of Pb+Zn. The anomaly pattern is much more clearly defined in this diagram, the stream sediment samples collected near the Bukit Bulat area containing a far higher quantity of these elements than any other area. The Hospital stream (A. Rumah Sakit) to the east of Bukit Bulat also contains high lead and zinc values, suggesting that any mineralisation in the Bukit Bulat area may extend slightly further east. Unfortunately samples were not collected from the A. Rumput Pait further to the west, so that the westward extension of the area with lead-zinc mineralisation can not be estimated. All the other areas mentioned during the discussion of the lead and zinc contents of soil samples previously can also be seen more clearly.

Figure 33 shows a map of the Co+Cu+Ni content of stream sediment samples. These elements all have moderately high correlation coefficients with each other, suggesting the possibility that these elements are derived from ultra-basic or basic rocks. The fact that a coherent pattern is not present suggests that a single area containing such rocks is not present, though these elements may be derived from some of the basic dykes present in the area.

Figure 34A is a map of the ratio Mn:Pb+Zn ratio in each stream sediment sample. Samples from streams in the Bukit Bulat area clearly have a much lower Mn:Pb+Zn ratio than samples from the streams draining the Mangani and Rumput Pait Vein areas. This suggests that the influence of Mn scavenging is not large in the Bukit Bulat area, though this process may have affected the lead and zinc concentration in streams draining the Rumput Pait and Mangani Vein areas.

Figure 34B is a map of the ratio Mn:Co+Cu+Ni in stream sediment samples from the Mangani area. This map is quite similar to the Mn distribution map, except that those samples containing high Co+Cu+Ni have lower values on this map. This suggests that Co+Cu+Ni have not been affected by Mn scavenging, and that these elements also did not originate from the same sources.

Figure 35 shows a map of the Mn and Fe content of soil samples. Fe+10xMn has been used, as this gives an approximately equal weight to both Mn and Fe, Fe being approximately 10 times as abundant as Mn in Mangani soil samples. This map shows that the extent of the variation of Fe+10xMn is not as large as the range of the contents of some of the other elements. The Bukit Bulat area has high values for these elements, and samples near the stream to the east of the Mangani Vein also consistently show high values of Fe+10xMn. These last high values may have resulted from seepage from the Mangani Vein, as these all occur in samples collected at the base of slope. Many of the samples from areas which contain high amounts of the elements (discussed previously) also contain high quantities of Fe+10xMn. This suggests that Mn and Fe scavenging may have had more effect on the element concentrations in soils than in streams, though obviously these high values may be due to the high percentage of pyrite and Mn minerals in mineralisation at Mangani.

Figure 36A shows the Pb+Zn contents of Mangani soil samples. In the previous discussion of lead and zinc contents in soil samples, a number of areas containing high amounts of these elements were pointed out. These areas can be seen much more easily on the combined element map, as the contrast between the highest and the lowest element contents in samples has been enhanced. The Bukit Bulat area is again notable for the high Pb+Zn content.

Figure 36B shows the Cu+Co+Ni+Cr content of the soil samples from the Mangani area. This map shows a similar pattern to the Cr soil content map, suggesting that despite Co, Cu and Ni having moderately high correlation coefficients with each other, their distribution in soil samples is not related to any lithology, or mineralised area visible on this map scale. High values of Cu+Co+Ni+Cr are mainly related to the area of outcrop of the Mangani Volcanic Formation. One exception is the Bukit Bulat area, where high values of Cu+Co+Ni+Cr are not caused by large concentrations of any individual element. This suggests that Cu, Co, Ni and Cr may be associated with the mineralisation in this area, though such elements do not appear to occur in large quantities in samples from the known areas of mineralisation.

Figure 37A shows the Fe+10xMn:Pb+Zn ratio in soil samples. To some extent this map is the reverse of the Pb+Zn map, which again suggests that scavenging has not resulted in false anomalies in the Mangani area. One exception to this may be the stream east of the Mangani Mine stream (A. Tambang).

Figure 37B shows the ratio Fe+10xMn:Cu+Co+Ni+Cr in soil samples. The area of outcrop of the Mangani Volcanic Formation has low values for this ratio, which is caused by the high Cr contents in this area. The Bukit Bulat area has high values for this ratio, suggesting that the high Cu+Co+Ni+Cr content in this area described previously may be a result of scavenging.

Meyer et al. (1977) suggest that regardless of the size fraction, anomalies are better defined by the ratios of the target metal to Fe and Mn. The previous section has demonstrated that this is true for the stream sediment samples, and also to some extent for the soil samples. However, the greatest value of such ratio maps is considered to be in identifying areas where Mn and Fe scavenging has played a large role.

The areas considered to be of most interest for further examination are marked on Figure 36A.

3.6 Conclusions relating to the soil and stream sediment geochemistry

Generally the stream sediment samples are much more successful in delineating clearly anomalous areas, and give a better indication of the proximity to known mineralisation than the soil samples. The lack of a coherent pattern from the soil samples may be due to the small size of some of the veins, which may only be producing narrow anomalous zones. Soil samples collected by the Indonesian Geological Survey (Machali et al. 1976) were more closely spaced than the samples taken during the present survey, and failed to delineate some of the known veins effectively.

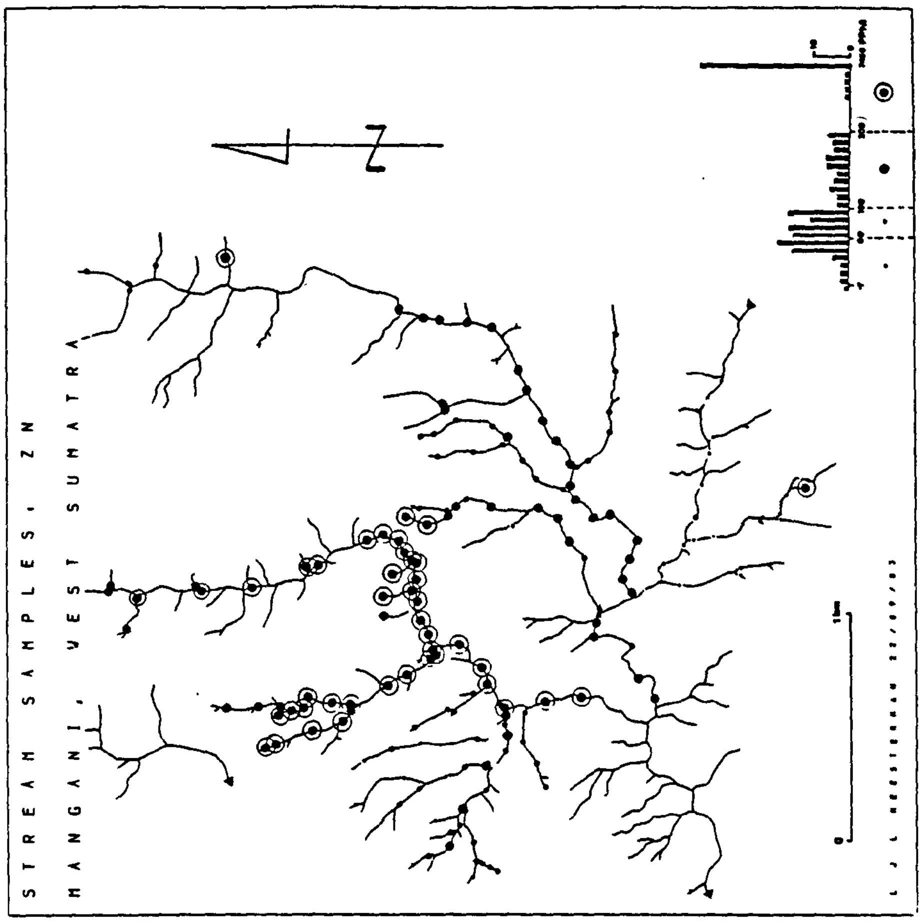
The stream sediment geochemistry very clearly shows that the Bukit Bulat area is anomalous for lead, zinc and manganese, though a number of other elements present in samples near known veins are not present in very large amounts. Gold and silver are present in a few of the samples from this area, though generally in small amounts. Mapping during the present investigation has resulted in the discovery of a number of previously unknown outcrops of mineralisation in streams both east and west of the hill. Soil samples from the hill ridge are also anomalous for several elements, suggesting that this area is extensively mineralised. This is the area considered to be most important for further, more detailed investigation.

A, B and C in Figure 36A mark areas in which it is considered that mineralisation may be present. Samples in streams to the north of the Hospital Vein, as well as samples to the north of known mineralisation in the S. Rumah Potong contain high element abundances, suggesting that mineralisation may be located further to the north. Soil samples from area A to the north of these streams are also anomalous, suggesting that this area should also be investigated further.

Area B is similarly anomalous for many elements, and rock outcrops near this area are highly pyritised. However this area may possibly be contaminated by material falling from the aerial cableway, which passed above this area.

Area C is interesting as many of the soil samples contain gold. This may be due to analytical error, as these samples were all analysed in the same batch, but the stream sediment samples from the S. Rumah Potong to the west also contain gold. One possibility is that there is a N-S vein along this ridge. Alternatively the gold in the stream sediment samples may be derived from the Helena Vein, and the samples along the ridge contaminated during analysis.

Isolated stream sediment samples with high element contents from the southern part of the area may be related to the mineralisation at Pagadis, where large blocks of ore with a high gold and siver content were found in volcanics, but could not be traced to their source.


STREAM SAMPLES. ZN
MANGANI, WEST SUMATRA

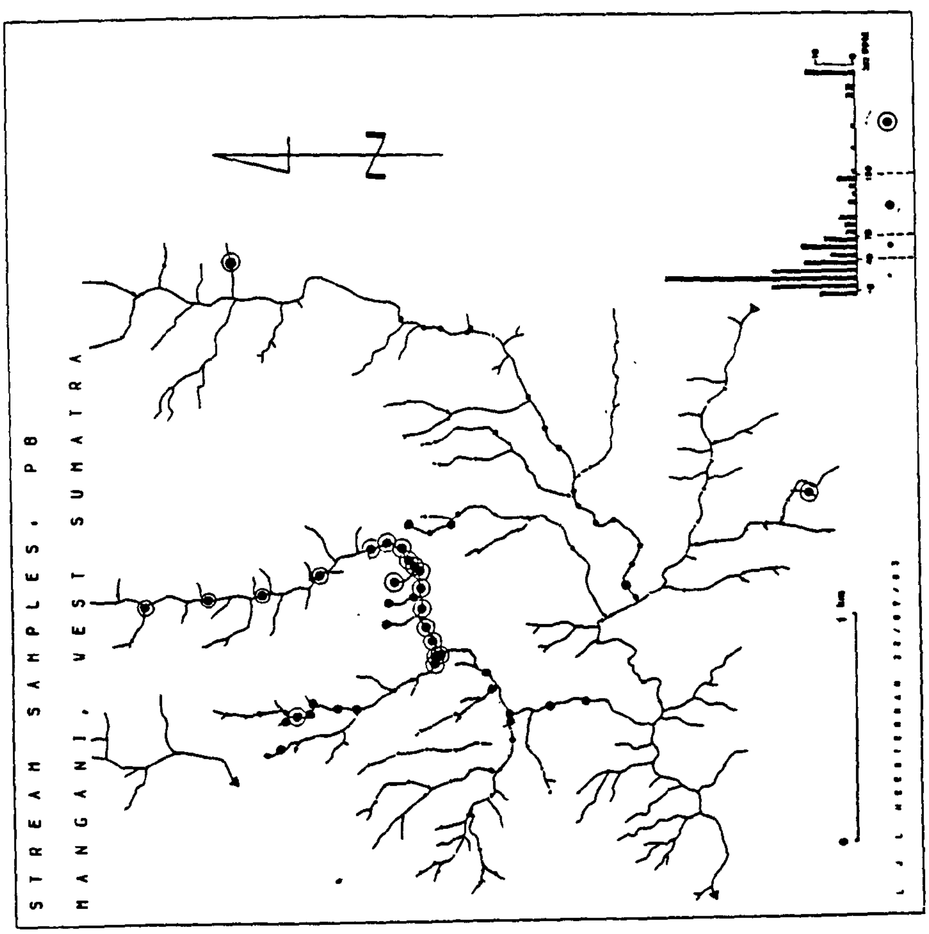
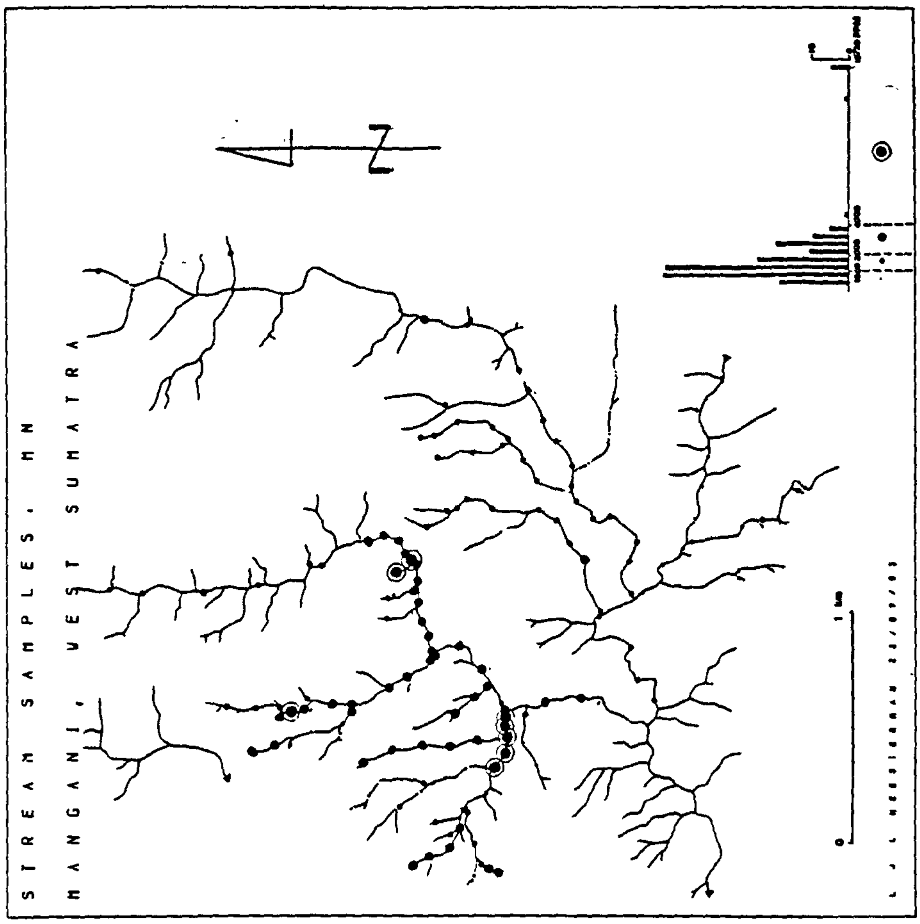

STREAM SAMPLES. PB
MANGANI, WEST SUMATRA

Figure 20


STREAM SAMPLES, MN
MANGANI, WEST SUMATRA

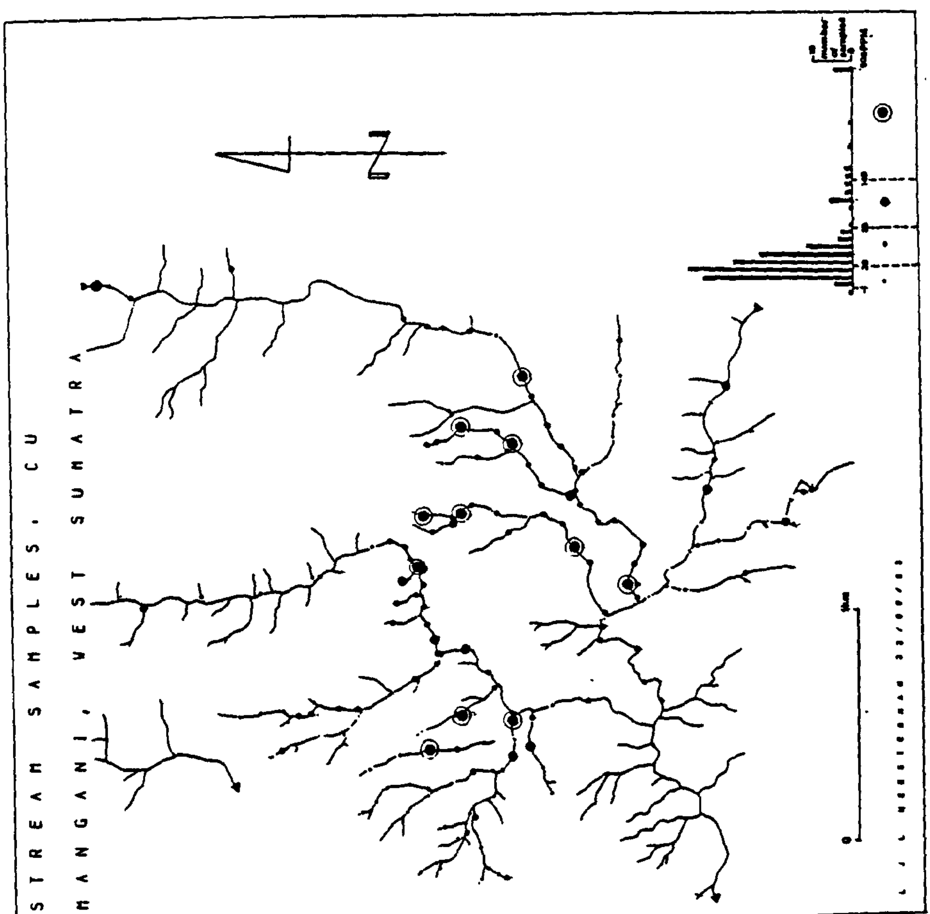
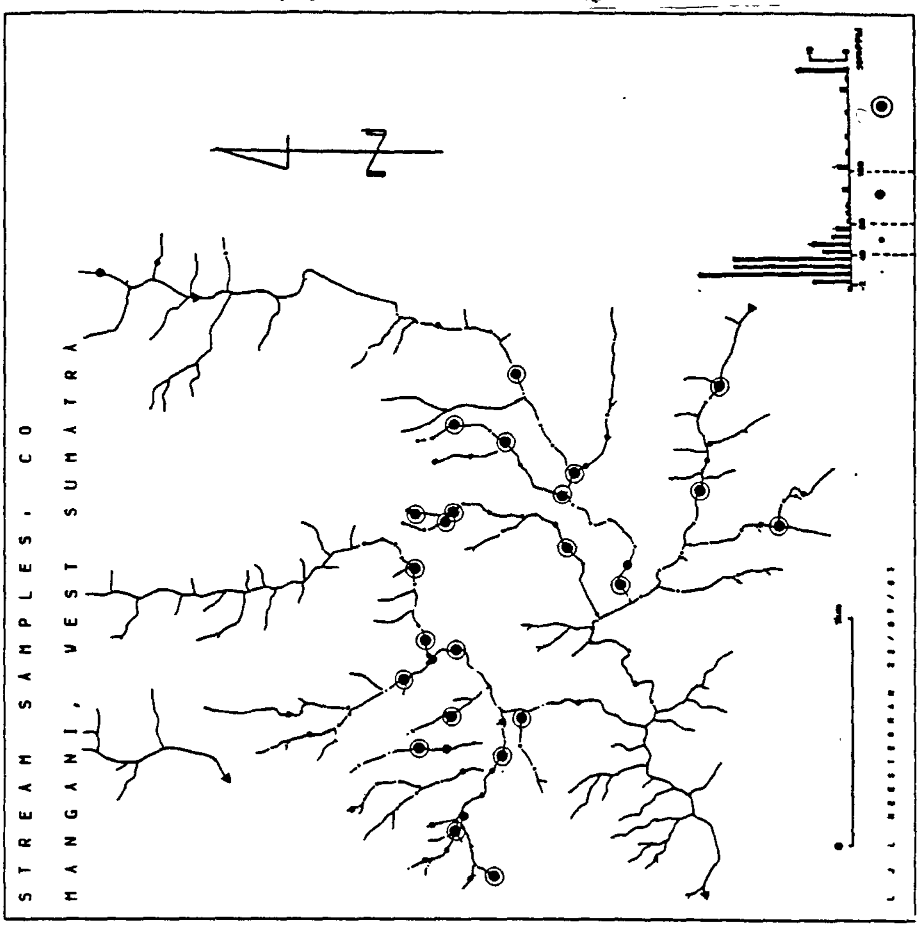

STREAM SAMPLES, CU
MANGANI, WEST SUMATRA

Figure 21


STREAM SAMPLES. CO
MANGANI, WEST SUMATRA

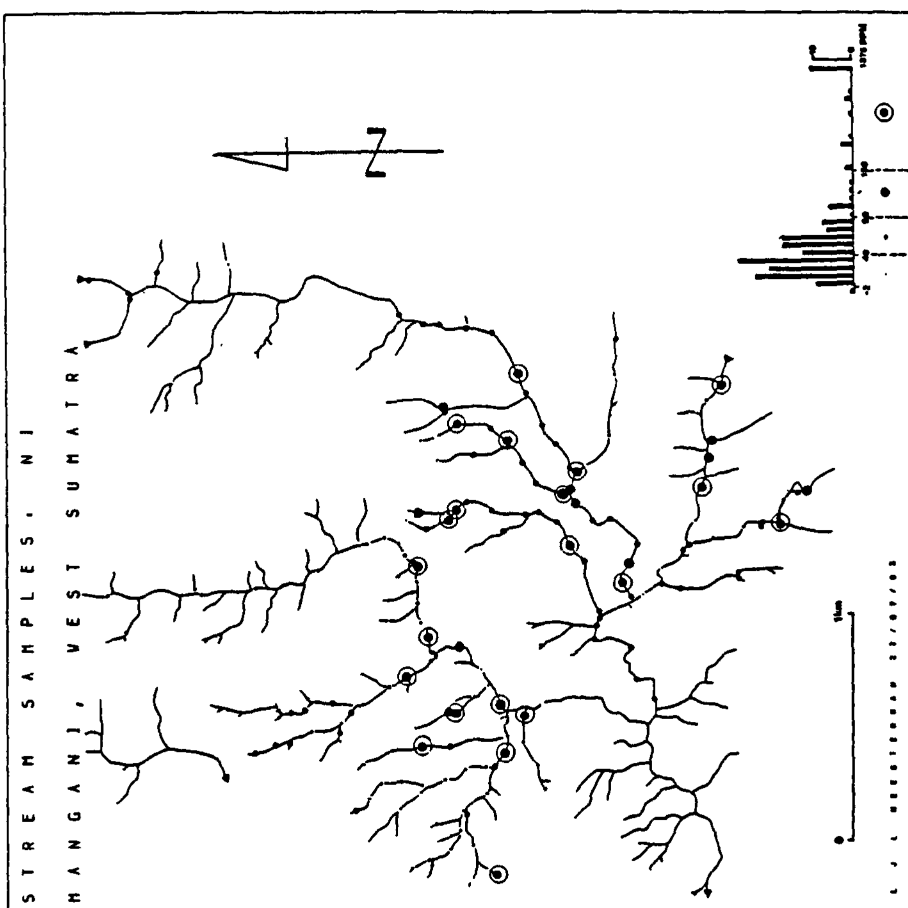
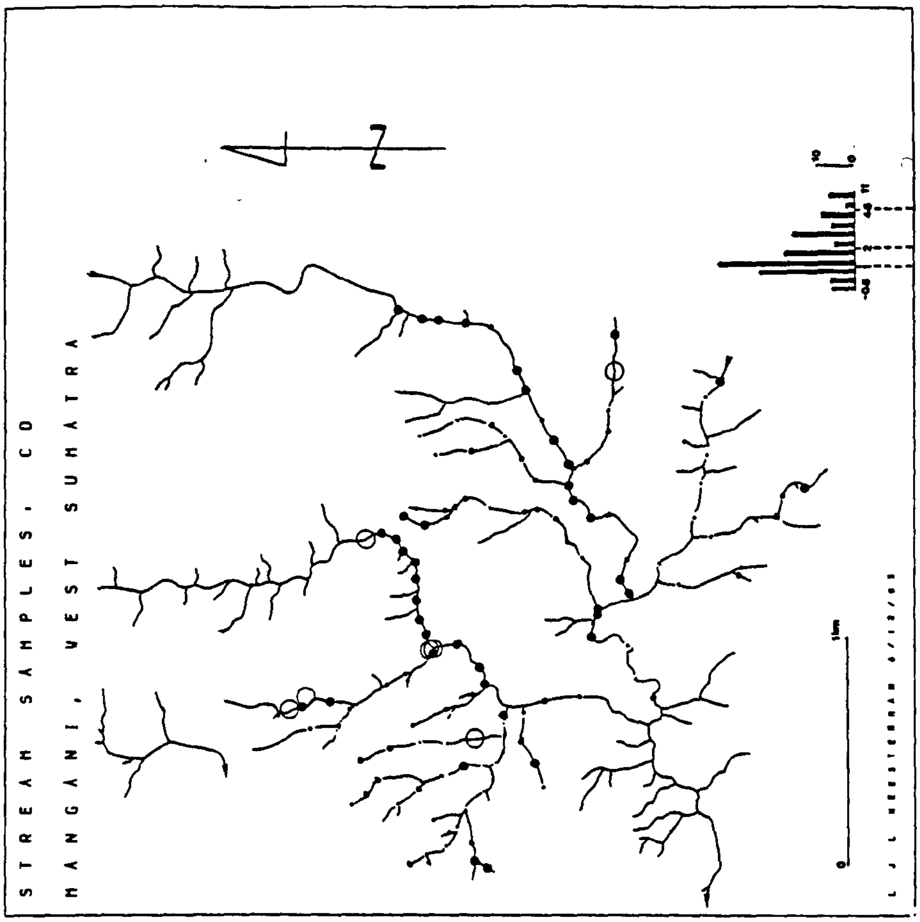

STREAM SAMPLES. NI
MANGANI, WEST SUMATRA

Figure 22


STREAM SAMPLES. CO
MANGANI, WEST SUMATRA

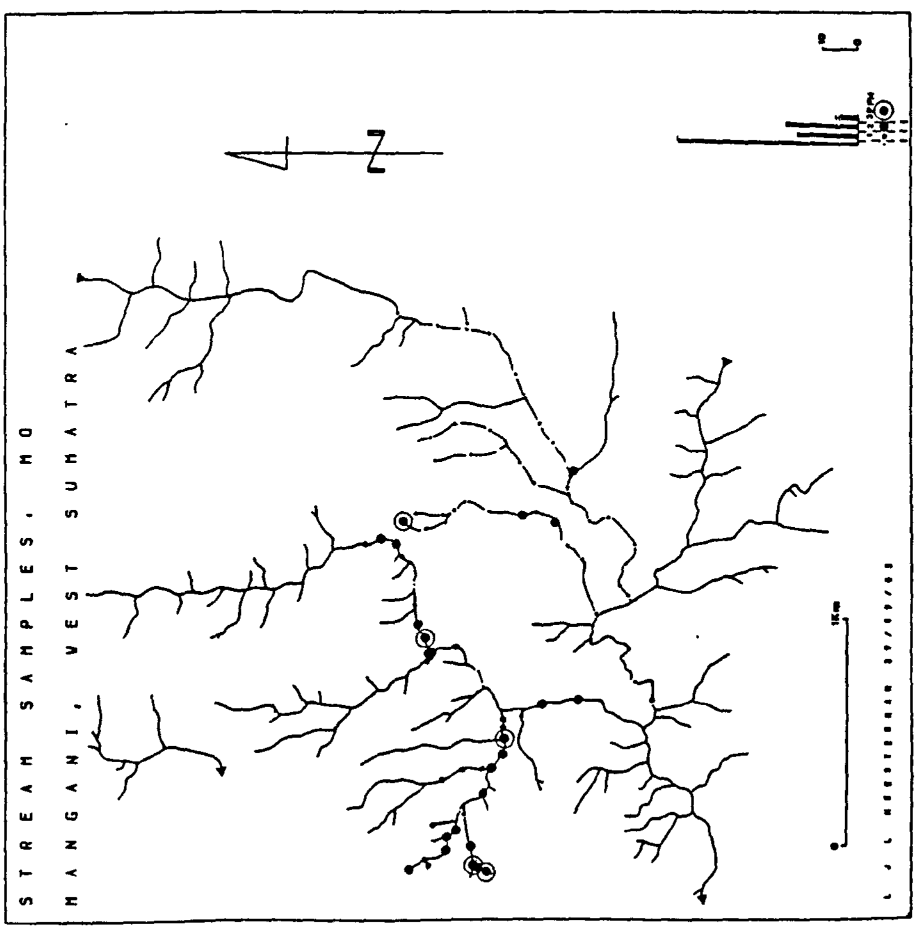
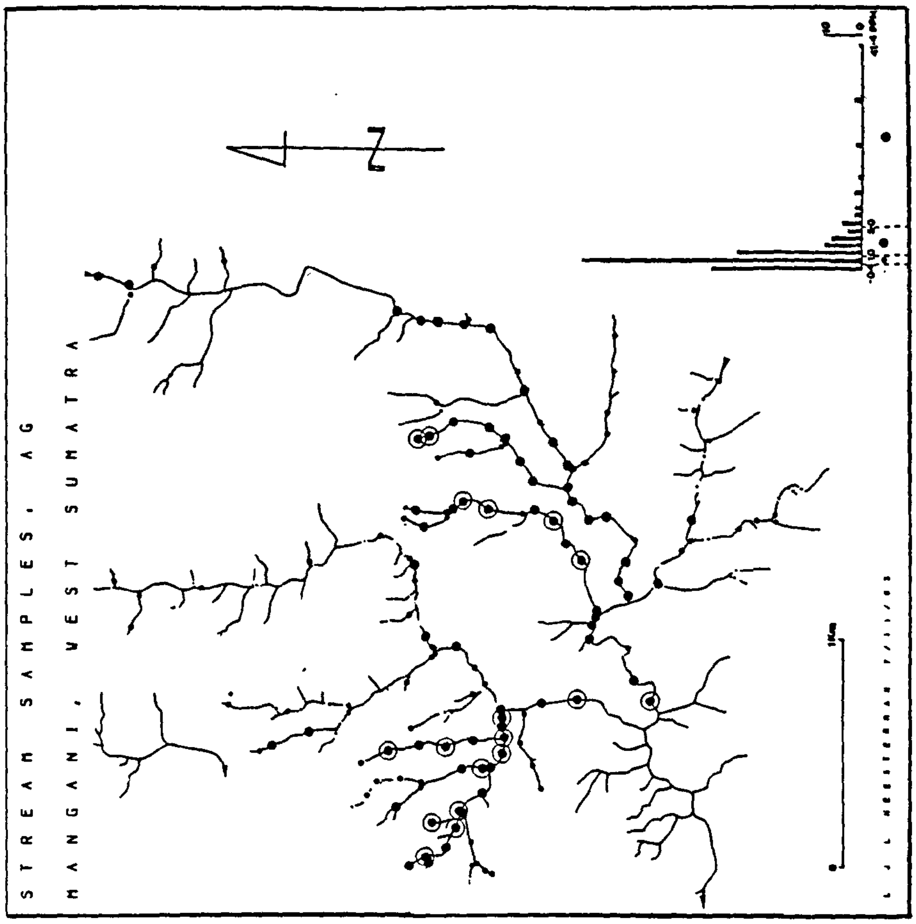

STREAM SAMPLES. MO
MANGANI, WEST SUMATRA

Figure 23


STREAM SAMPLES, AG
MANGANI, WEST SUMATRA
1Km

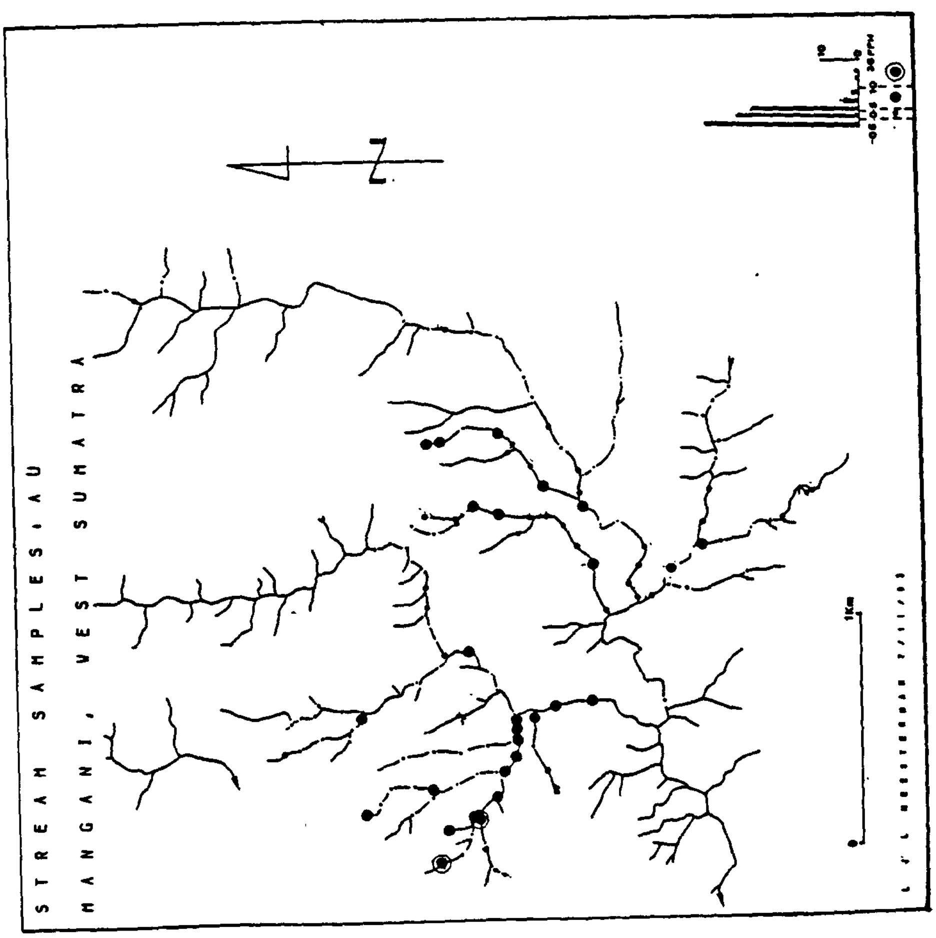
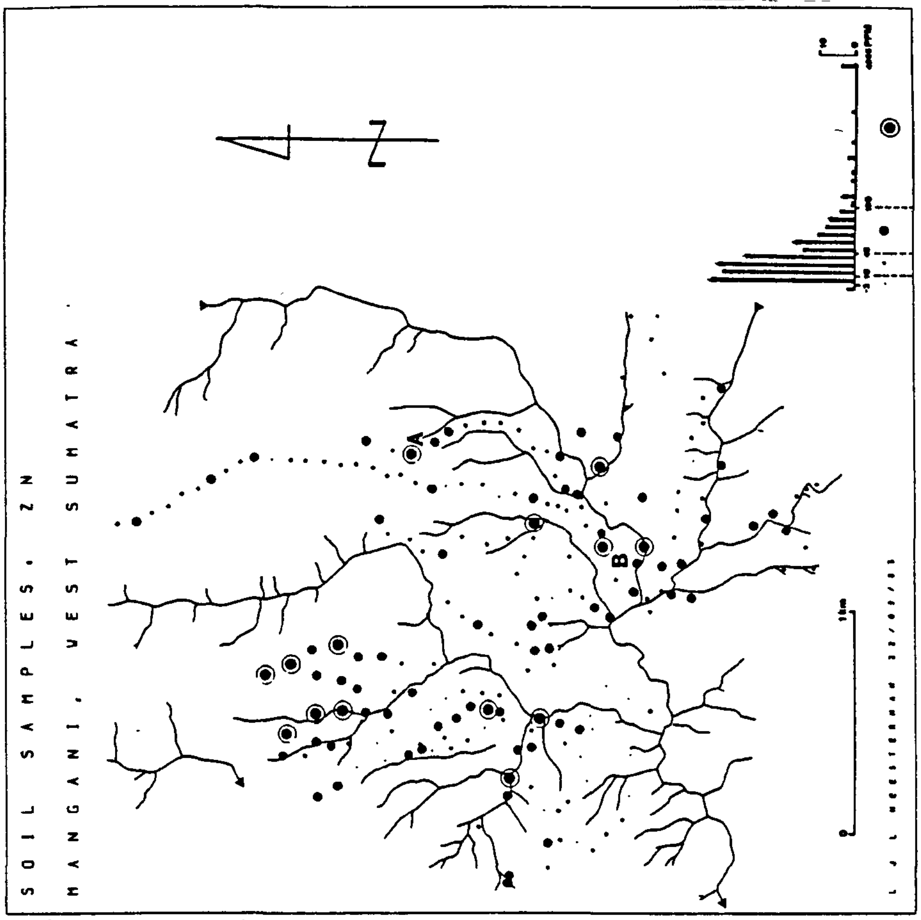

STREAM SAMPLES, AU
MANGANI, WEST SUMATRA
1Km

Figure 24


SOIL SAMPLES. ZN
MANGANI, WEST SUMATRA
A
B
1km

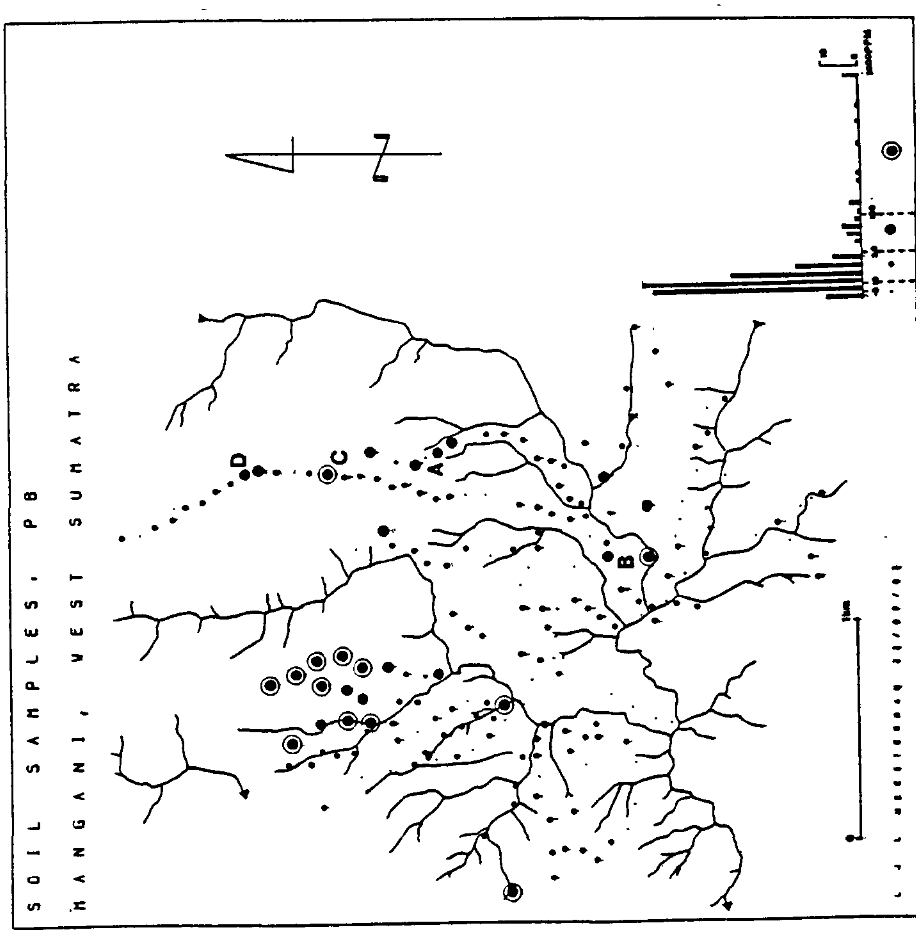
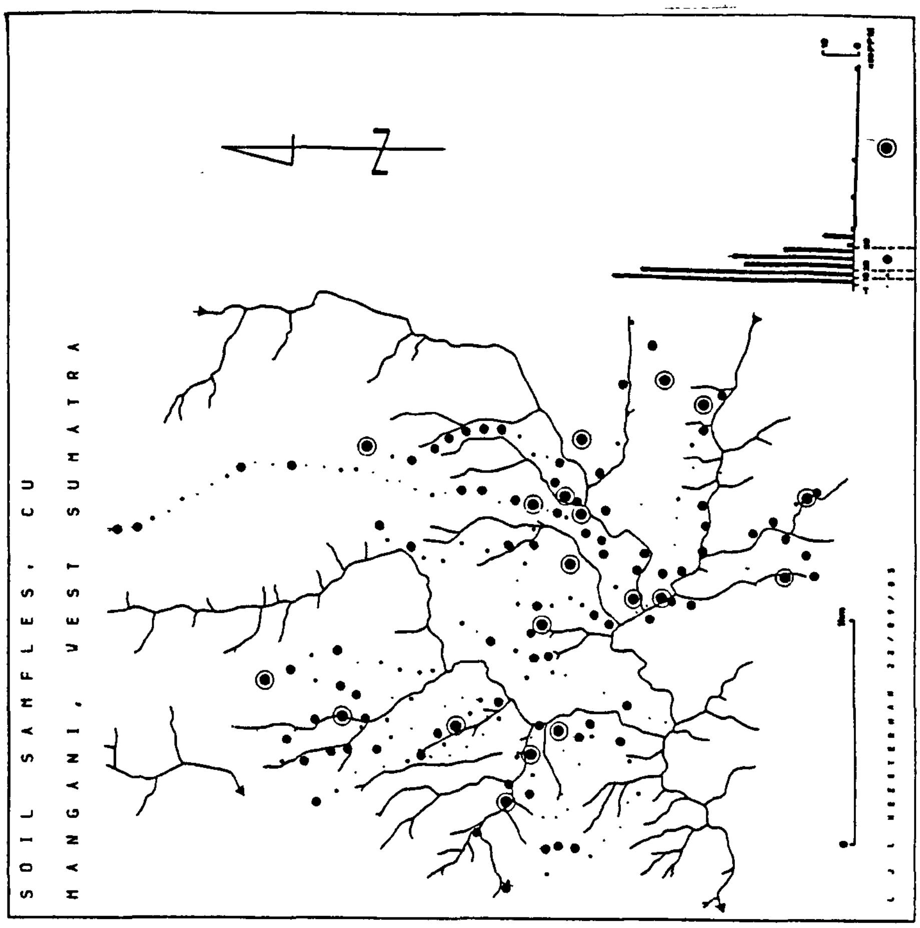
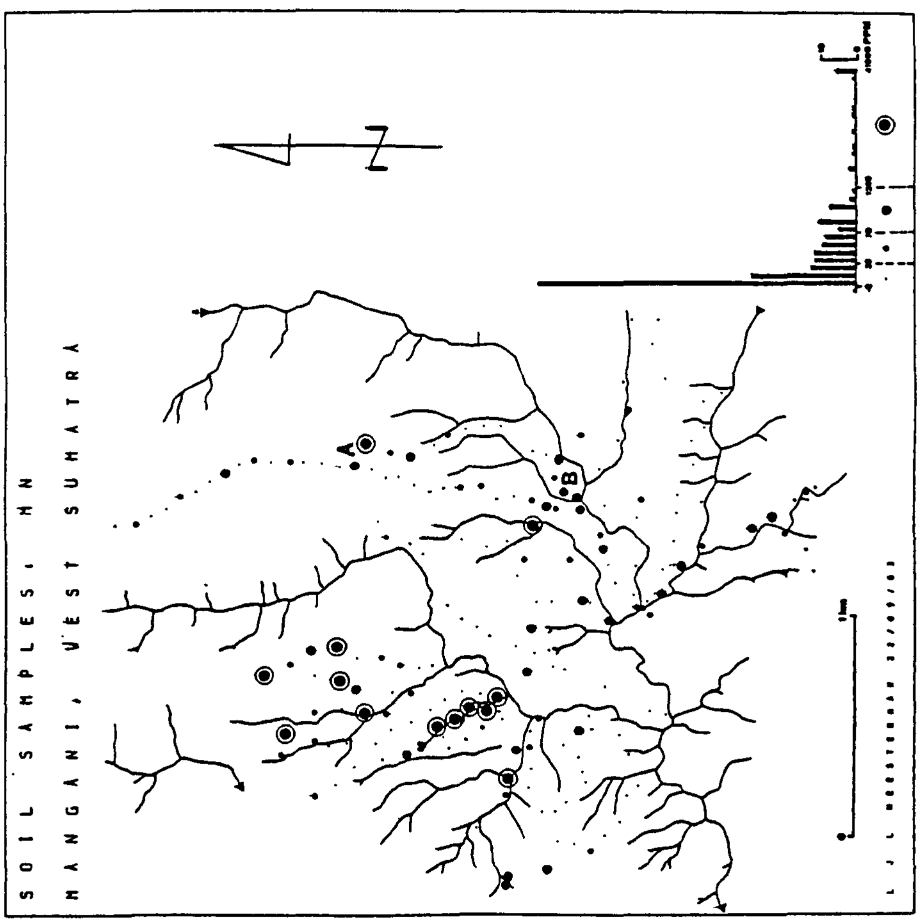
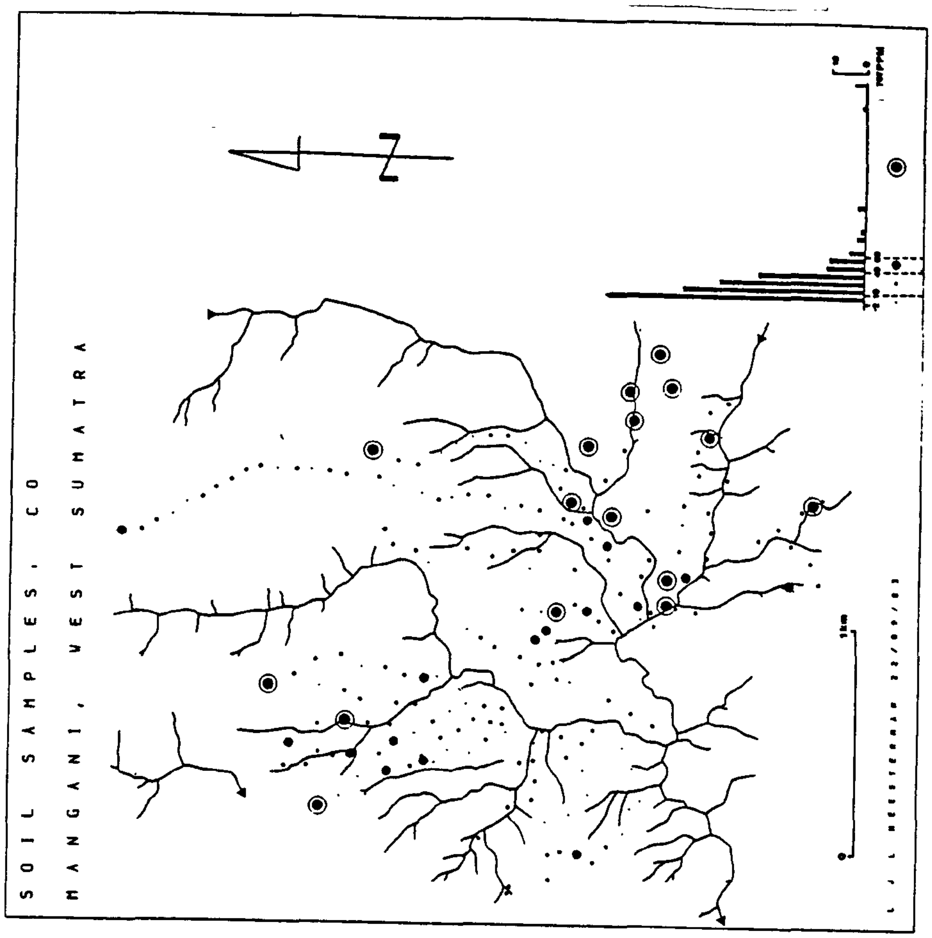

SOIL SAMPLES. PB
MANGANI, WEST SUMATRA
A
B
C
D
1km

Figure 25


SOIL SAMPLES, CU
MANGANI, VEST SUMATRA


SOIL SAMPLES, MN
MANGANI, VEST SUMATRA
A
B


SOIL SAMPLES, CO
MANGANI, WEST SUMATRA

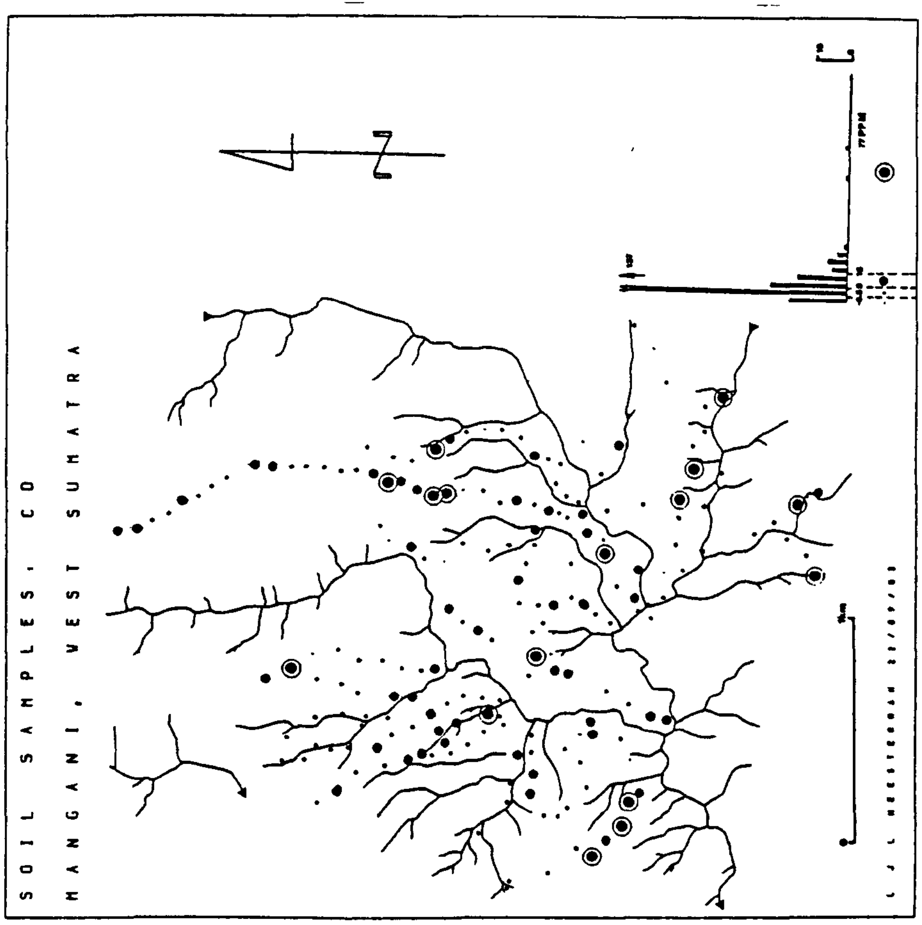

SOIL SAMPLES, CO
MANGANI, WEST SUMATRA

Figure 27

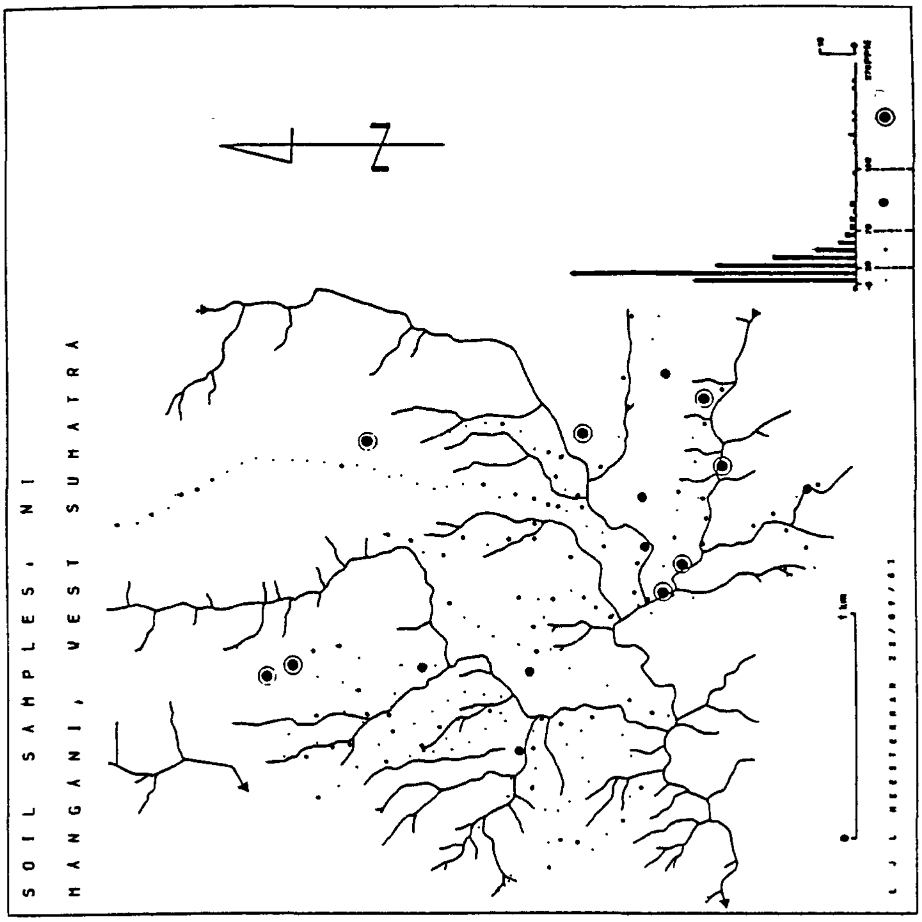
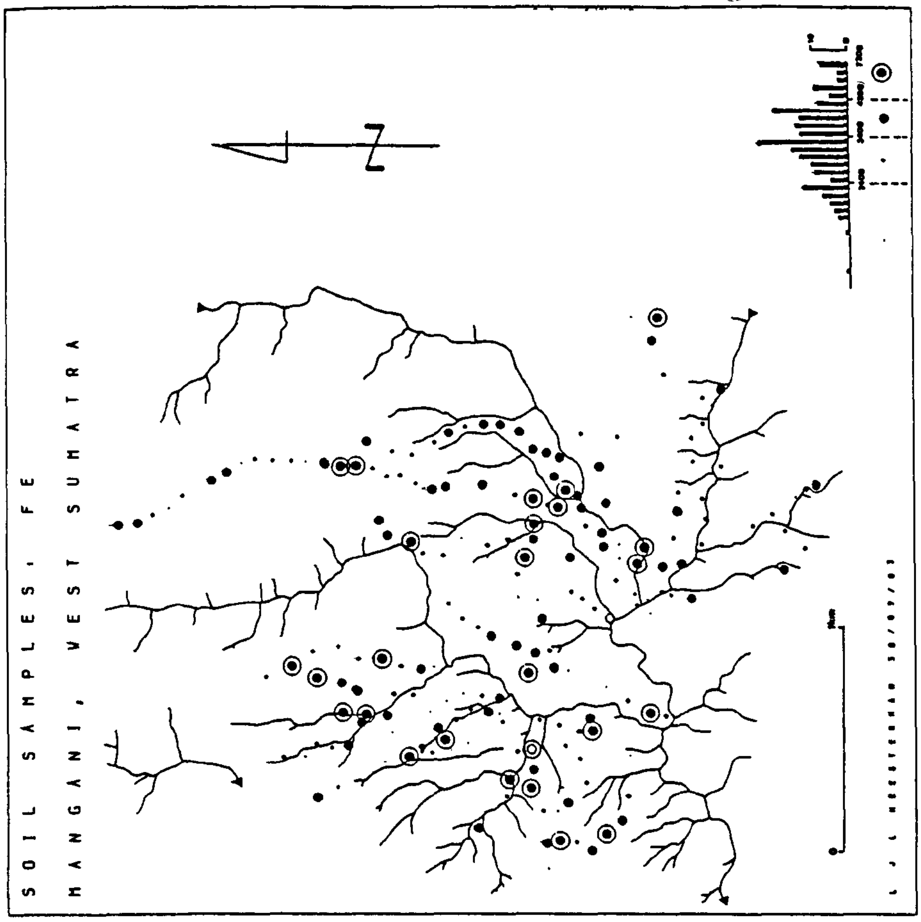


Figure 28


SOIL SAMPLES. FE
MANGANI, WEST SUMATRA

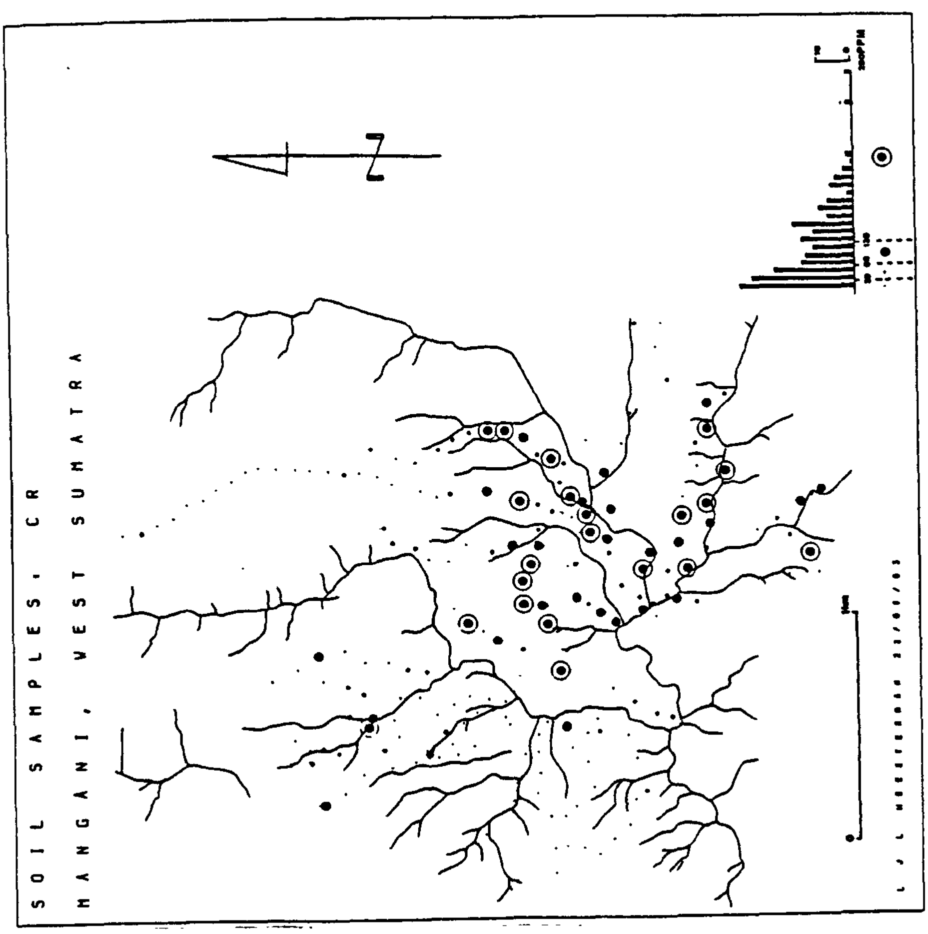
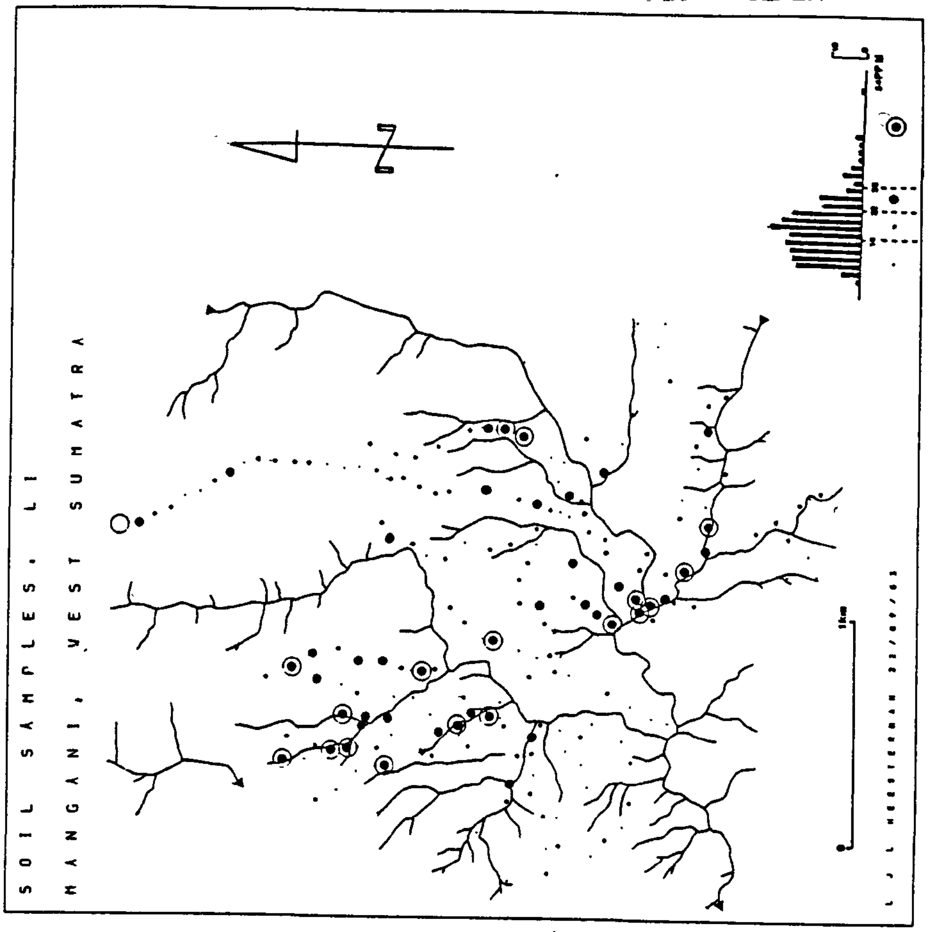
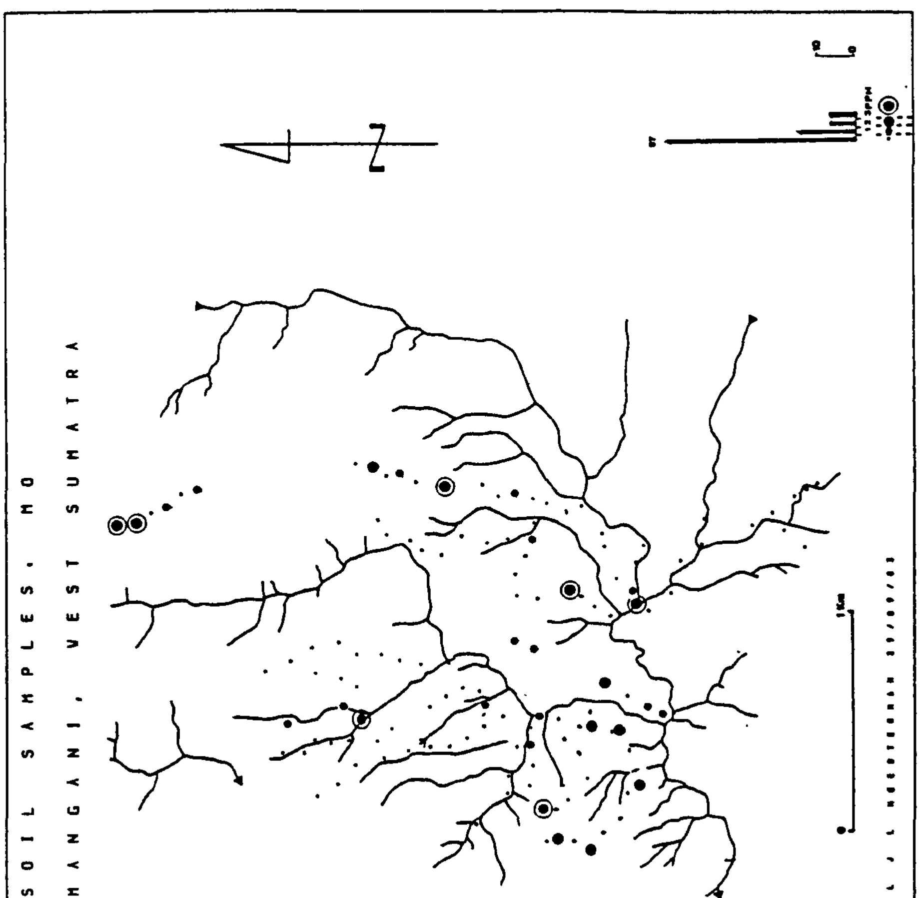
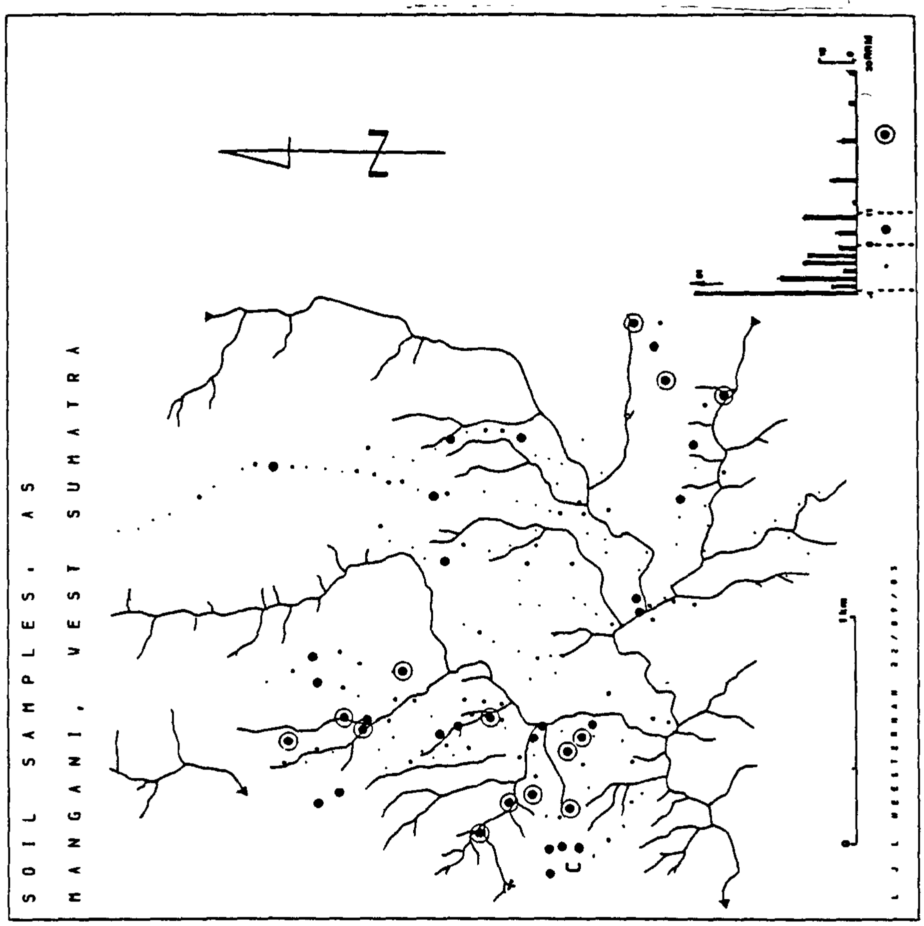

SOIL SAMPLES. CR
MANGANI, WEST SUMATRA

Figure 29


SOIL SAMPLES. LI
MANGANI, WEST SUMATRA
1km


SOIL SAMPLES. MO
MANGANI, WEST SUMATRA
1km


SOIL SAMPLES, AS
MANGANI, WEST SUMATRA

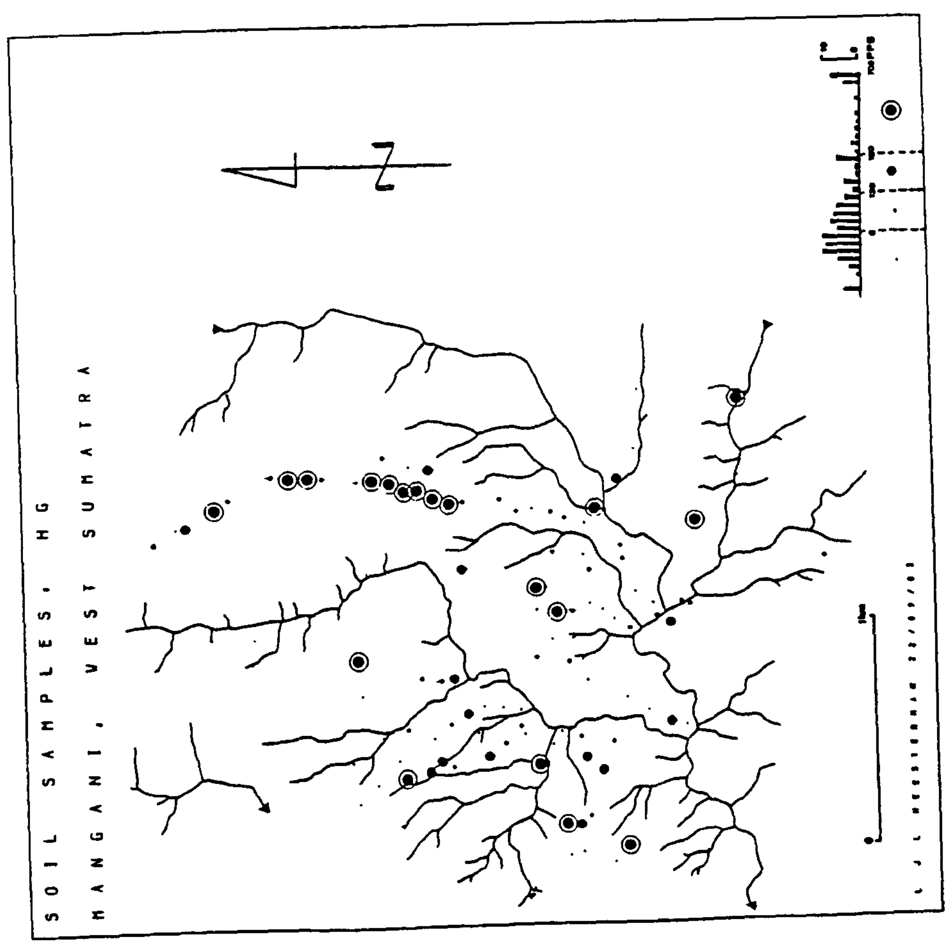
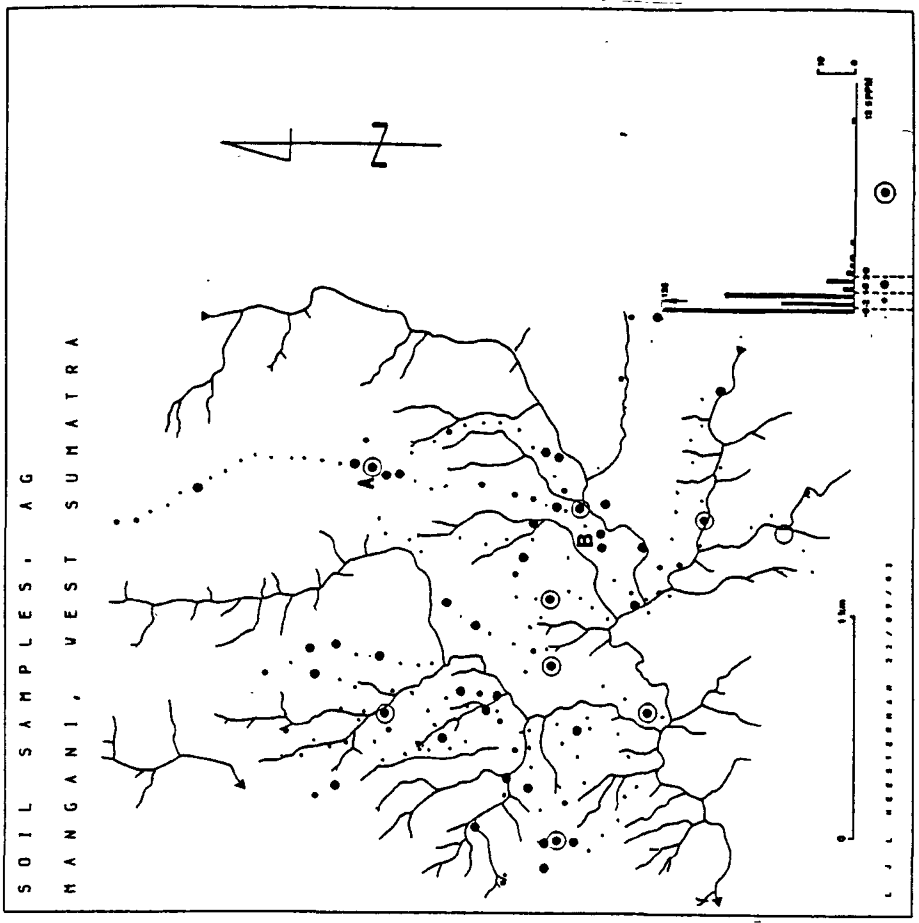

SOIL SAMPLES, HG
MANGANI, WEST SUMATRA

Figure 31


SOIL SAMPLES, AG
MANGANI, WEST SUMATRA
A
B
1 km

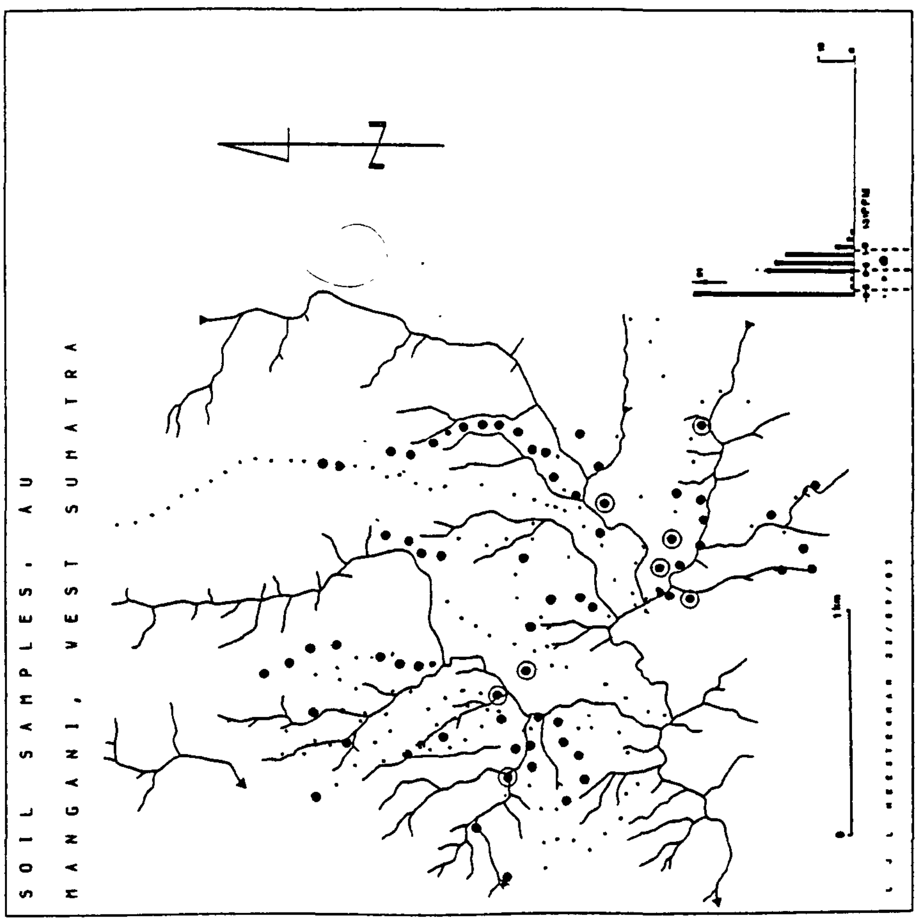

SOIL SAMPLES, AU
MANGANI, WEST SUMATRA
1 km

Figure 32

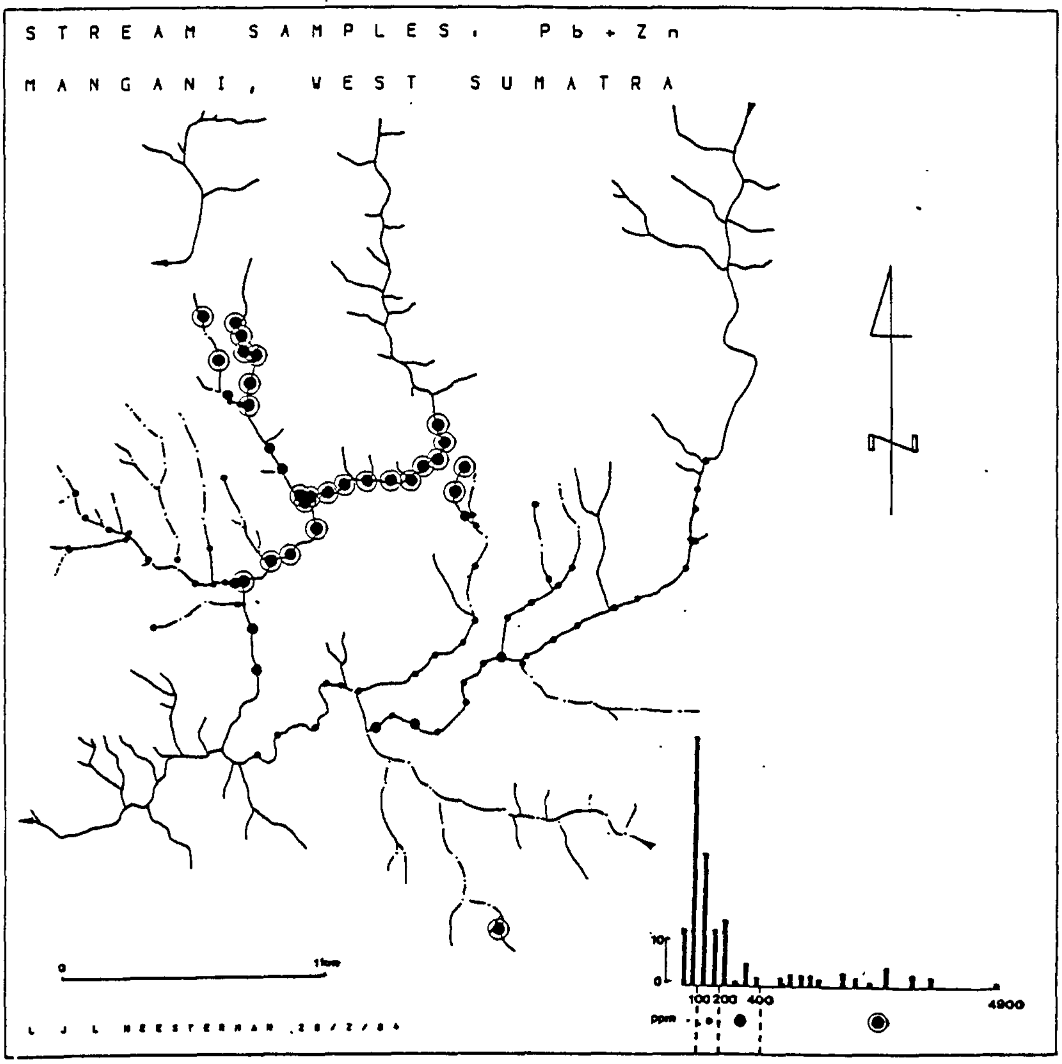

STREAM SAMPLES, Pb+Zn
MANGANI, WEST SUMATRA
0
1km
10
0
100 200 400
4900
ppm

Figure 33

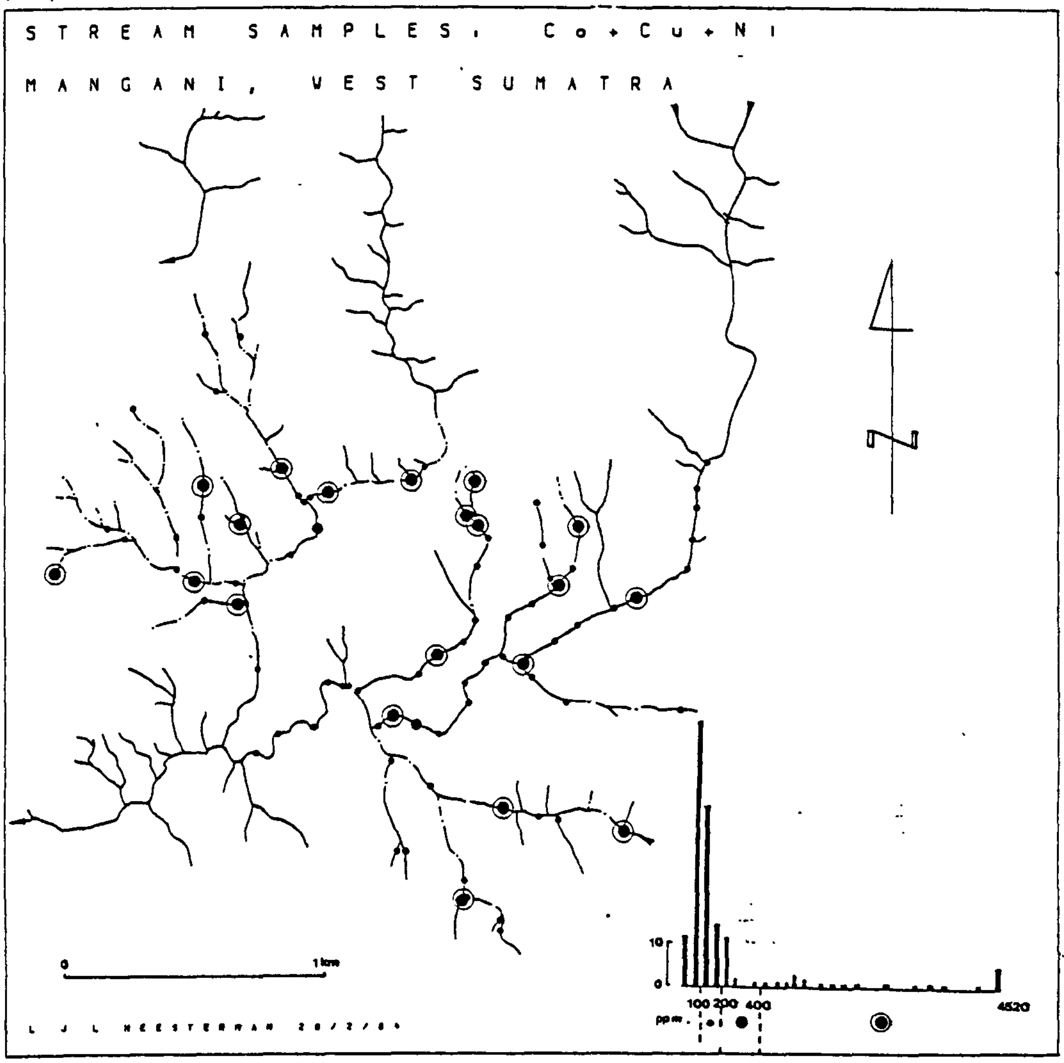
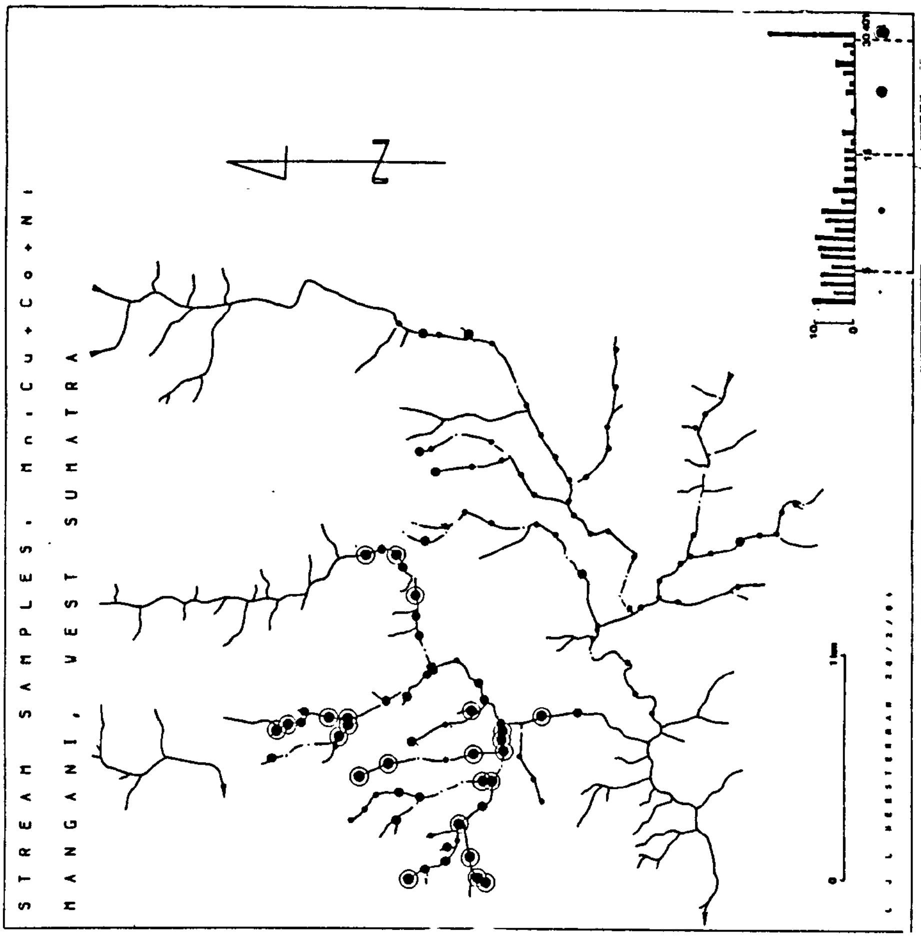

STREAM SAMPLES, Co+Cu+Ni
MANGANI, WEST SUMATRA
0
1 km
10
0
100
200
400
4520
ppm

Figure 34


STREAM SAMPLES. Mn. Cu + Co + Ni
MANGANI, WEST SUMATRA

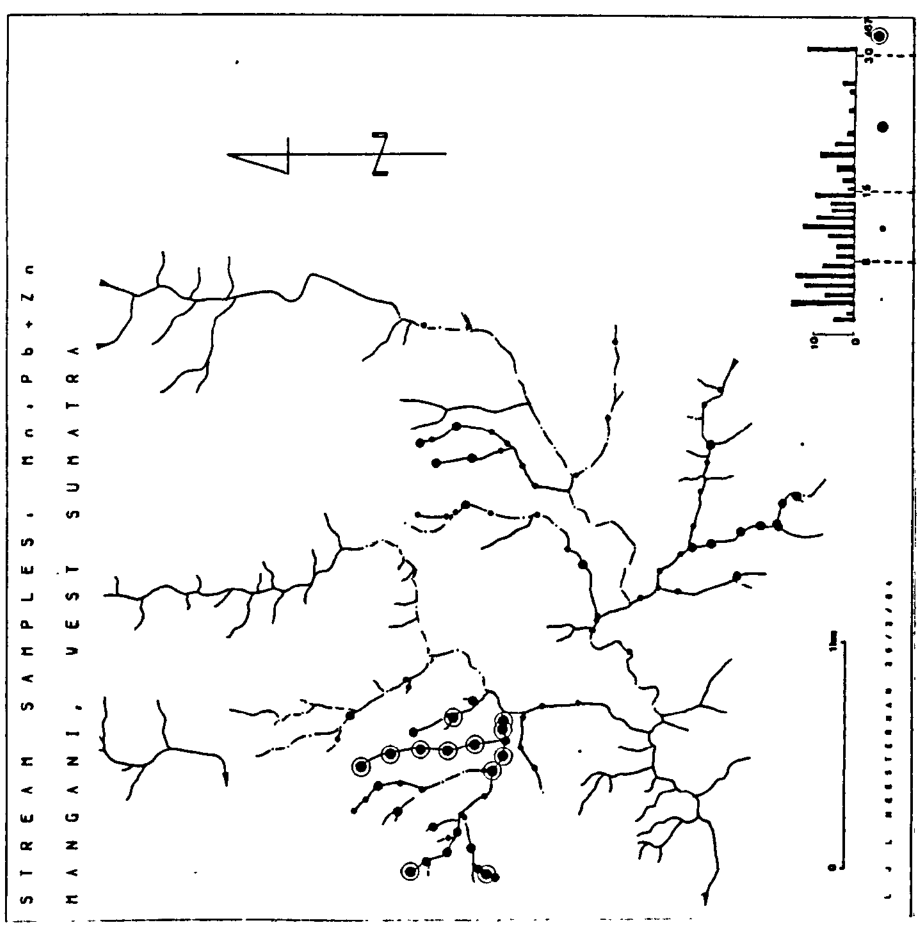

STREAM SAMPLES. Mn, Pb + Zn
MANGANI, WEST SUMATRA

Figure 35

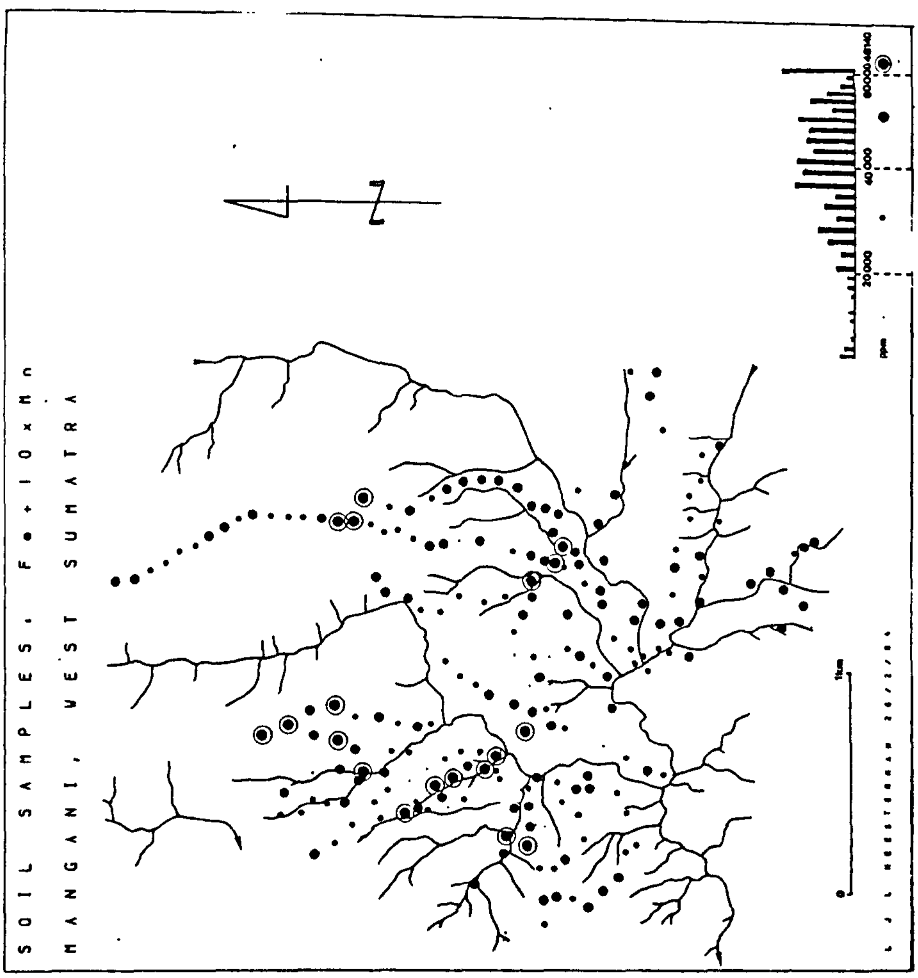
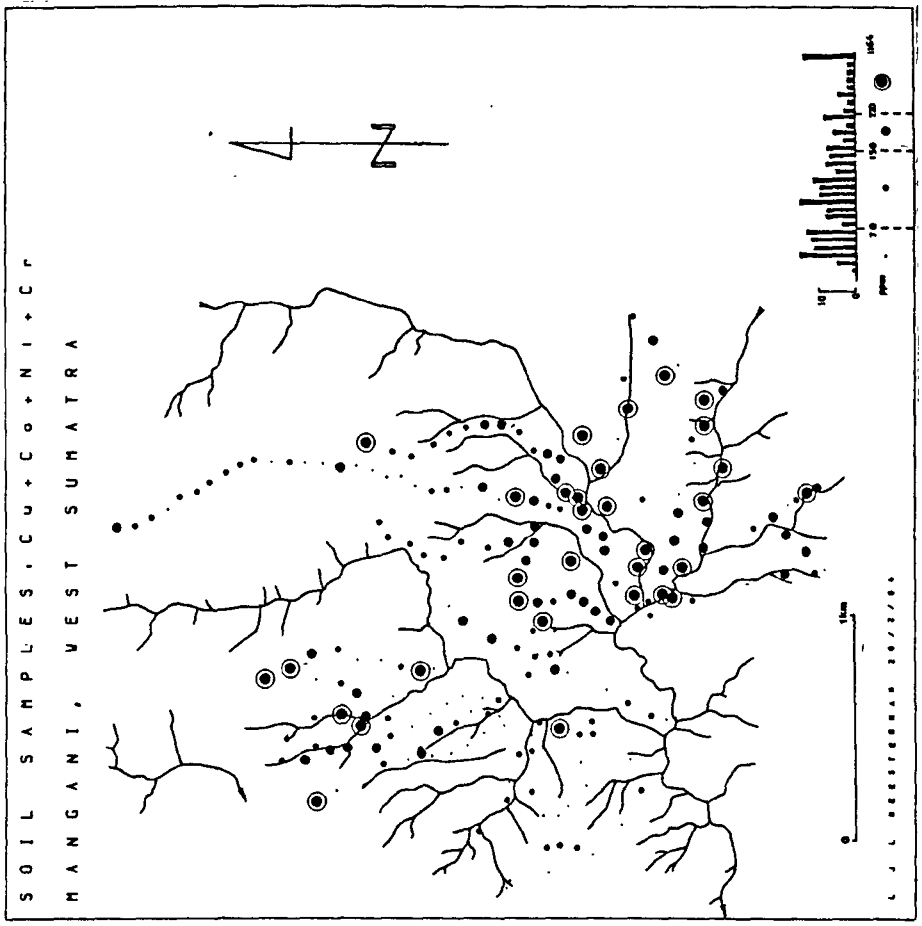


Figure 36


SOIL SAMPLES, Cu+Co+Ni+Cr
MANGANI, VEST SUMATRA

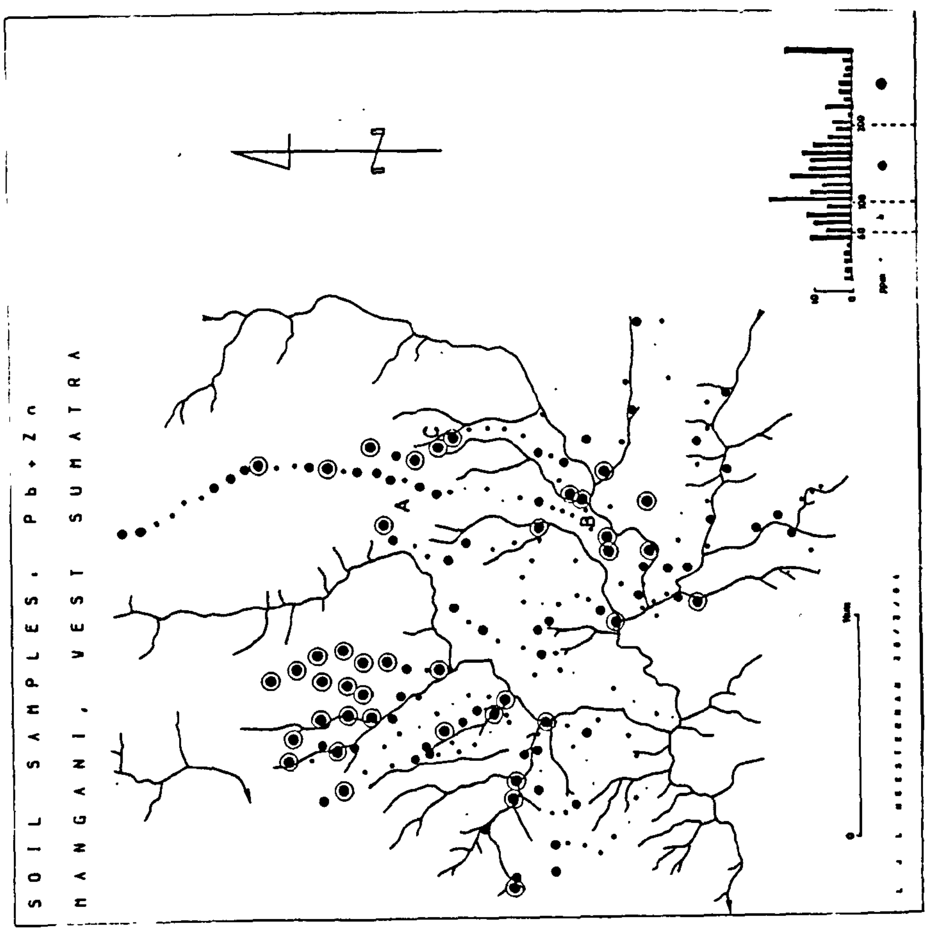
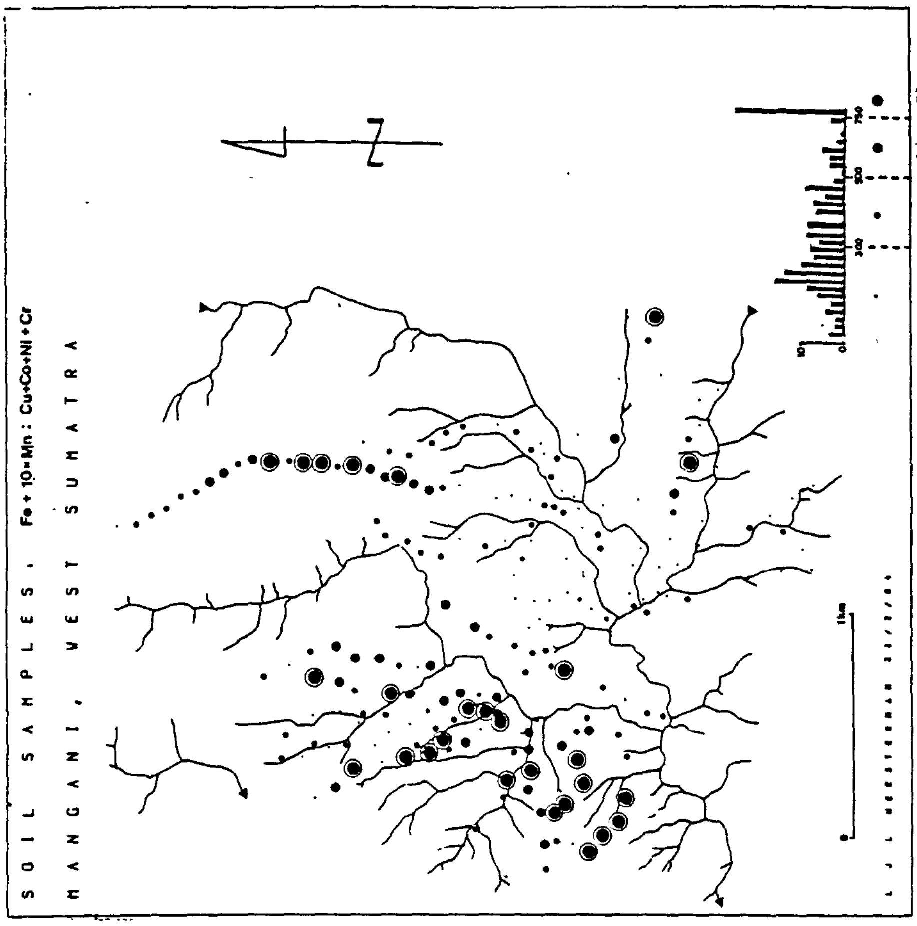
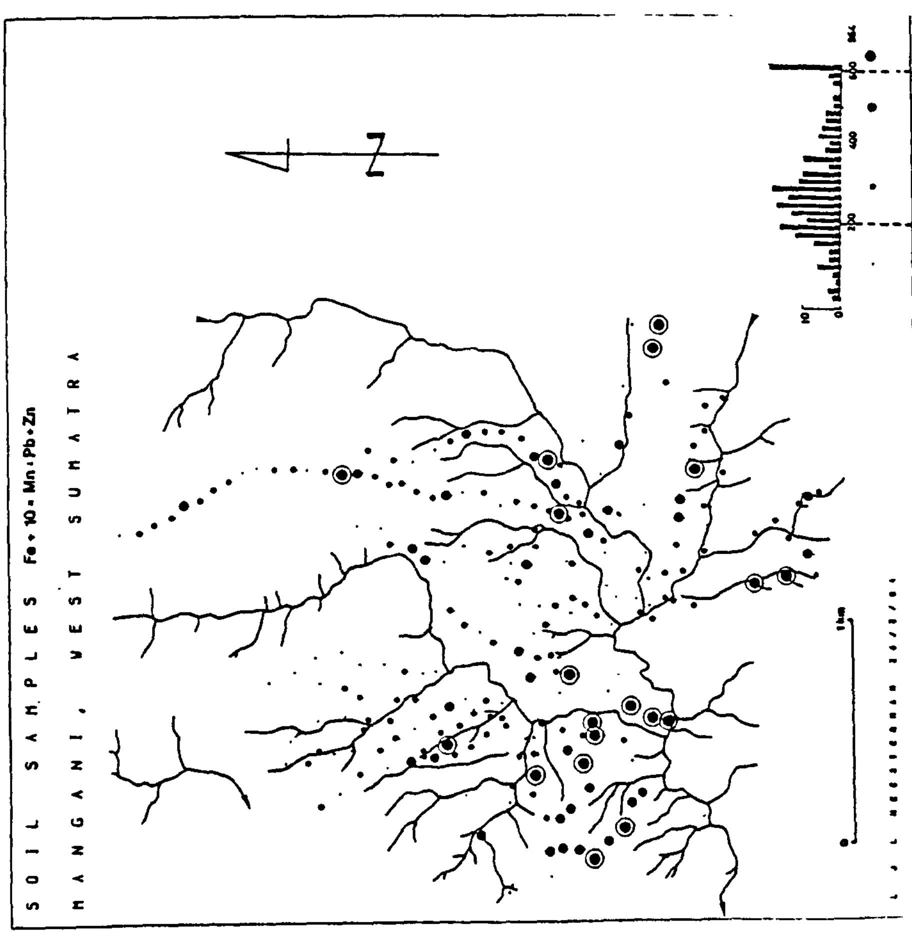

SOIL SAMPLES, Pb+Zn
MANGANI, VEST SUMATRA

Figure 37


SOIL SAMPLES, Fe+10·Mn : Cu+Co+Ni+Cr
MANGANI, WEST SUMATRA
1km


SOIL SAMPLES Fe+10·Mn·Pb+Zn
MANGANI, WEST SUMATRA
1km

Chapter 4

Mineralisation at Mangani.

4.1 Introduction.

Mapping at Mangani during the present survey has resulted in doubling the number of mineral veins known, though some of these may be extensions of the same vein system into adjacent stream valleys. All the mineral veins are marked on Figure 5, except the Serassah Vein which is located in head waters of the S. Botung, and the Tumbuk Vein, which occurs on the SE flanks of B. Guntung.

Most veins have been sampled, and examined in the field and in thin section. Samples of hydrothermally altered rock have also been analysed, to investigate the possibility that the alteration has been accompanied by the introduction of valuable elements. All analyses were done at outside commercial laboratories by CSR Ltd, so the details of the analytical methods are not known. Unless otherwise stated, all samples are channel samples, though most specimens of altered rocks were grab samples. Analytical results from the M.M. Aequator annual reports have been quoted in dwt/ton or g/tonne, but yearly reports only give the abbr viation "t", and as the yearly reports occasionally give vein widths in yards, and precious metal contents in grammes, it is possible that other imperial and metric measurements were interchanged.

The geological setting of many of the veins has been investigated in detail. In most cases the areas around the veins have been mapped at 1:500, though in some cases these maps have been reduced to 1:1000 for presentation in this thesis.

In the following account, each of the areas of mineralisation is described separately. The relationships between the different veins, and the different types of mineralisation present are discussed in the final section of this chapter, and then possible factors which may have affected the mode of formation of the mineralisation in this area are discussed.

4.2 The Mangani Vein

4.2.1 Introduction.

This was the main vein mined at Mangani. The Mangani vein was discovered in 1907, and in 1914 M.M. Aequator started working the mine. The name of the vein is derived from the very high manganese content, which is still evident in the A. Tambang (Fig. 5), which runs dry as the water now travels through the mine. The stream bed has been cemented by such large amounts of manganese oxides that it looks like black concrete (Plate 13a).

In 1931 the mine was closed down due to exhaustion of reserves, and in 1934 the concession was transferred to M.M. Barisan. In 1938 the concession was taken over by the Marsman Mining Company (Philippines), who worked the Rambutan and Silver veins. At the end of World War II the mine shafts were blown up by the Japanese, and the mine abandoned. Table VI shows the gold and silver produced in the Mangani area.

Power for the mine was derived from hydro-electricity. One turbine was located at the Rambutan processing plant, with water derived from the upper reaches of the Botung and Botung Lawas Rivers. Water was also carried in tunnels in the side of the gorge below the Brani Vein for several kilometres, before falling down to the turbine. These tunnels are in very good condition, though locally silted up, and the remains of the turbine are still present (Plate 13b).

4.2.2 Literature.

The following published and unpublished documents relate to the Mangani Mine, and contain details of the mining operation, and analytical results.

Technical report by S.J. Truscott to the directors of the West Sumatra Mijnen Syndicaat (W.S.M.S), in Rotterdam, 2nd Sept 1910,

Report by G.A. Wright to the directors of the Mangani Consortium in Gera-Untermhaus. 4th Feb 1911.

Report by C.A. Erhardt to the W.S.M.S on 28th March 1911.

The Aequator Mining Company yearly reports, 1914, 1915, 1920, 1921, 1922, 1923, 1924, 1925, 1926, 1927,

Table VI Gold and silver production from the Mangani mine.

Mangani Aequator (1913-1932)

Year	Au kg	Ag kg	value (guilders)	Tonnage	Au millheads g/ton	Ag millheads g/ton
1913	2.261	288.998	17,857	750?	7.7	1074.8
1914	17.874	2,733.385	160,817	6,510		
1915	177.718	19,204.931	1,138,952	25,125		
1916	212.259	23,058.798	1,269,848	32,529		
1917	195.503	17,786.329	1,260,863	40,299		
1918	127.950	12,217.484	1,010,374	15,713		
1918	63.897	8,285.743	752,584	?		
1919	75.930	11,638.690	1,164,653	10,835		
1920	110.245	10,898.442	1,172,481	30,342		
1921	108.698	7,408.222	644,356	23,303	5.7	317.9
1922	212.971	6,233.868	748,164	32,516	7.0	265.9
1923	249.040	11,007.791	1,051,421	46,375		
1924	364.018	11,514.294	1,281,305	60,866		
1925	560.819	16,671.882	1,910,091	81,814	7.3	281.0
1926	497.505	15,577.929	1,490,583	80,001		
1927	462.217	14,671.633	1,439,088	80,006	6.7	277.8
1928	652.582	15,900.889	1,823,452	91,602	7.7	327.8
1929	567.512	12,889.939	1,490,149	84,716	7.1	247.3
1930	490.120	13,067.868	1,214,928	71,140	7.3	265.0
1931	354.262	6,194.688	728,108	34,645		
1932	7.516	90.716	14.417	682		
Total	5,510.887	237,342.509	21,784,497	849,769		

Mangani Marsman (1940-41)

Year	Au kg	Ag kg	value (guilders)	Tonnage
1940	149.170	4,321.287	405,124	41,945
1941	491.000	6,650.-	?	?
Total	640.170	10,971.287		

Total gold produced in the Mangani area 6,151.057 kg
" silver " " " " " 248,313.796 kg

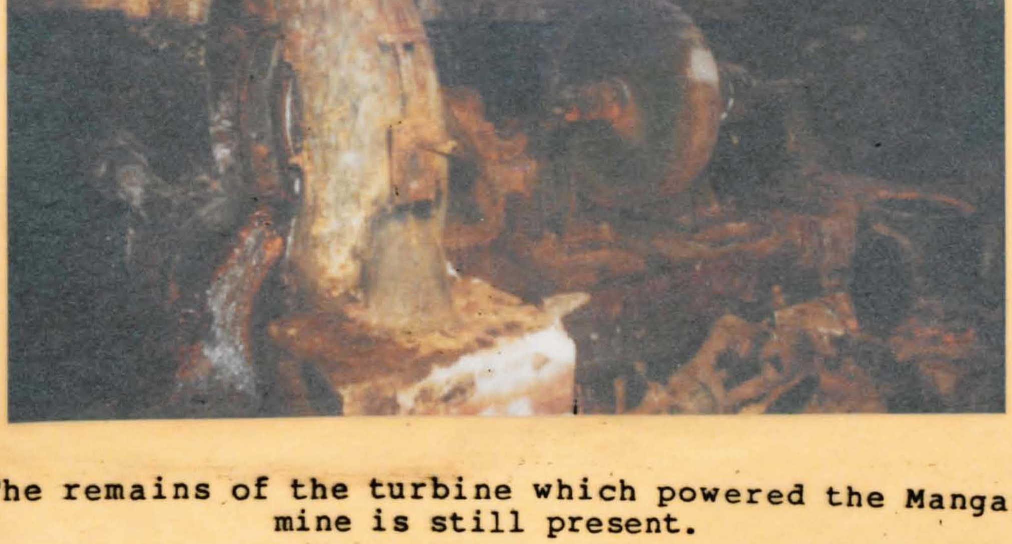
Plate 13

a. The stream bed of the A. Tambang to the east of the Mangani Vein is cemented by manganese oxides.

b. The remains of the turbine which powered the Mangani mine is still present.

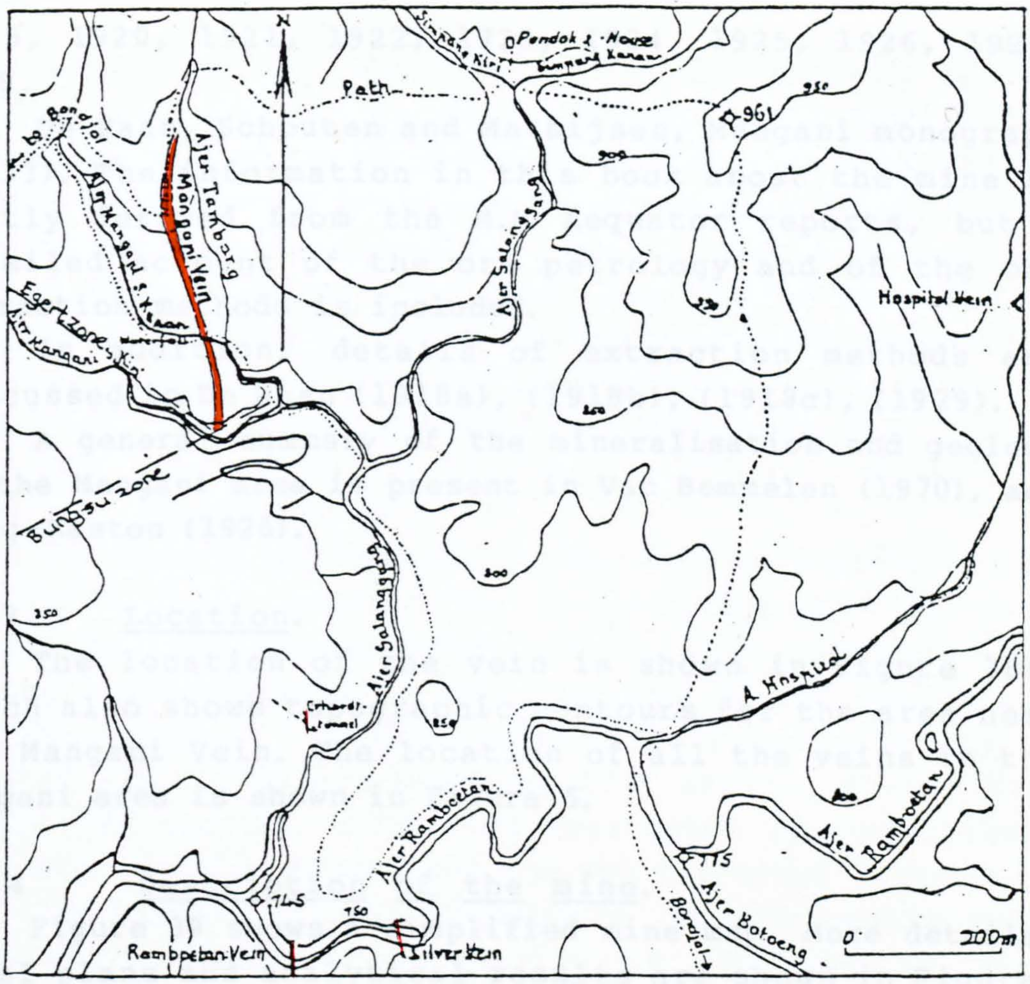
Plate 13

a. The stream bed of the A. Tambang to the east of the Mangani Vein is cemented by manganese oxides.

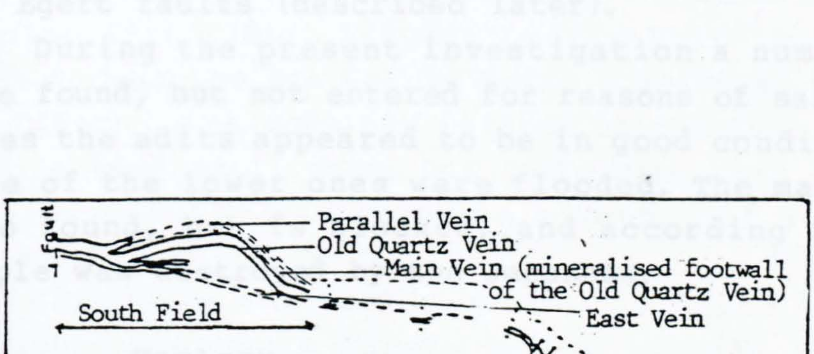


b. The remains of the turbine which powered the Mangani mine is still present.

Fig. 38



a. Map of the Mangani Vein area (modified after Wing-Easton, 1926).



b. Divisions of the Mangani Vein (after Wing-Easton, 1926)

1915, 1920, 1921, 1922, 1923, 1924, 1925, 1926, 1927, 1928.

De Haan, Schouten and Mathijsen, Mangani monograph (1933). The information in this book about the mine is partly derived from the M.M Aequator reports, but a detailed account of the ore petrology and of the ore extraction methods is included.

In addition, details of extraction methods are discussed in De Haan (1918a), (1918b), (1918c), (1929).

A general summary of the mineralisation and geology of the Mangani area is present in Van Bemmelen (1970), and Wing-Easton (1926).

4.2.3 Location.

The location of the vein is shown in Figure 38a, which also shows topographic contours for the area near the Mangani Vein. The location of all the veins in the Mangani area is shown in Figure 5.

4.2.4 Description of the mine.

Figure 39 shows a simplified mine map. More detailed level plans and analytical results are shown in Figures 40-47.

In addition to the adits and shafts built to exploit the ore, very long adits were driven along the Boengsoe and Egert faults (described later).

During the present investigation a number of adits were found, but not entered for reasons of safety. In most cases the adits appeared to be in good condition, though some of the lower ones were flooded. The main shaft was also found, but is blocked, and according to the local people was destroyed by the Japanese.

4.2.5 Geology.

A number of outcrops of the Mangani Vein occur in the A. Tambang (Mangani Mine Stream), and on the hillslopes to the west of this stream. These are marked on the geological map of the area (Enclosure 2). Unfortunately these outcrops are all very weathered. As the Mangani adits were not entered, very little new information about this vein could be gained.

The vein is hosted in volcanic rocks, with andesites and basalts in the south, the Mangani breccia in the middle, and dacites as well as some liparites in the north. At the extreme northern end of the mine Telisa Formation sediments are encountered. De Haan et al. (1933) reports details about specific samples, and their location in the mine. A summary of this information is given in Chapter 2. Outcrop along the A. Tambang (Mine stream) is limited, and all available information is marked on the geological map of the Mangani area (Enclosure 2).

4.2.6 Structure.

The overall orientation of the vein is reported to be 013/65^{o}E, but locally the orientation may be very different. The orientations of the vein outcrops seen during the present survey are marked on the geological map (Enclosure 2). Common orientations described by De Haan et al, (1933) are 045^{o} and 170^{o} strike, 45-80^{o} dip. Figure 38b shows a simplified horizontal section through the vein, and the names used for the different sections.

The Mangani Vein is an example of a composite vein, generally consisting of three parts. The Parallel Vein tends to occur in the footwall of the Main Vein, which itself lies in the footwall part of the Old Quartz Vein. The East Vein tends to stay in the hanging wall part of the vein complex, but cuts across the bend in the middle section (Fig. 38b). A Young Quartz Vein is also locally present near the Old Quartz Vein, considered by De Haan et al. (1933) to be possibly related to the East Vein. A West Vein, a very small vein, but containing very high precious metal contents, was found in a number of places west of the main group of veins.

Generally the combined vein consists of a southern section:- the South Field, and a northen section:- the North Field (Fig. 38b). These are connected by a disturbed and poorly mineralised section hosted in the Mangani Breccia. The South Field was the main part mined, and consisted of a southern, middle and northern part. These partitions were based on geological and mineralogical characteristics.

The middle part of the South Field was characterised by a sharp flexure found at all levels, though the East Vein is clearly younger as it cuts across this bend.

A pre-ore dyke is described (De Haan et al., 1933), as occurring along the 170^{o} zone to the south of the bend in the South Field. This may be a feldspar porphyry or tuffisite dyke similar to the dykes associated with some of the other veins.

At the southern end the vein is cut off by NE/SW trending cross fault (Boengsoe Zone). This may either be an antithetic sinistral fault related to movement on the SFS, or an extensional fracture related to tension within the Mangani Graben, if the interpretation of the Mangani structure proposed in Chapter 2, is valid. Another fault (Egert Zone) 20m to the west of the vein trends NW/SE, and was consired by De Haan et al. (1933) to separate the Rumput Pait from the Mangani Vein. The relationships between the different veins are dicussed at the end of this chapter. At the northern end of the Mangani Vein, where the vein is hosted in sediments, the vein appears to be cut off by a diagonal fault, or a fault along the vein, beyond which ore was disrupted, and had low metal value. Such a fault could be a dextral fault related to tensional movement within the Mangani Graben. A number of 170^{o} trending faults are described cutting the vein by De Haan et al. (1933), and are probably dextral synthetic faults related to movement on the SFS. In some cases De Haan et al. (1933) suggest that these faults occurred before the formation of the ore, and acted as barriers to the mineralising fluids, suggesting that fluid flowed along the vein, rather than rising up the fracture.

4.2.7 Petrology.

Samples were collected from the two outcrops of the Mangani Vein in the A. Tambang, and from a point on the hillslope to the west where local people had excavated part of the vein. All the in situ specimens from the Mangani Vein that were collected during the present investigation are highly weathered, though float from the stream contained good sulphidic specimens.

The vein material consists of sugary, watery or white, massive, porous or colloform banded quartz, veined and banded with limonitic material. One sample contained a vug which in the field appeared to be filled with graphitic material. This could not be confirmed in the laboratory, as the sample disintegrated in transit. Much of the rock is brecciated, and appears to contain the remains of dirty brown rock fragments, cemented by a network of quartz veinlets.

In thin section abundant small fluid inclusions can be seen in the earlier irregular quartz grains, some inclusions consisting of two phases. Later clear quartz crystals occasionally contain some fluid inclusions, but these are not as abundant. Haematitic bands are thought to have formed as a result of weathering of pyrite veinlets, and some recognisable pyrite crystals can still be seen scattered throughout the rock. The remains of rock fragments can be identified due to the presence of finer grained material, partly overgrown by irregular quartz grains.

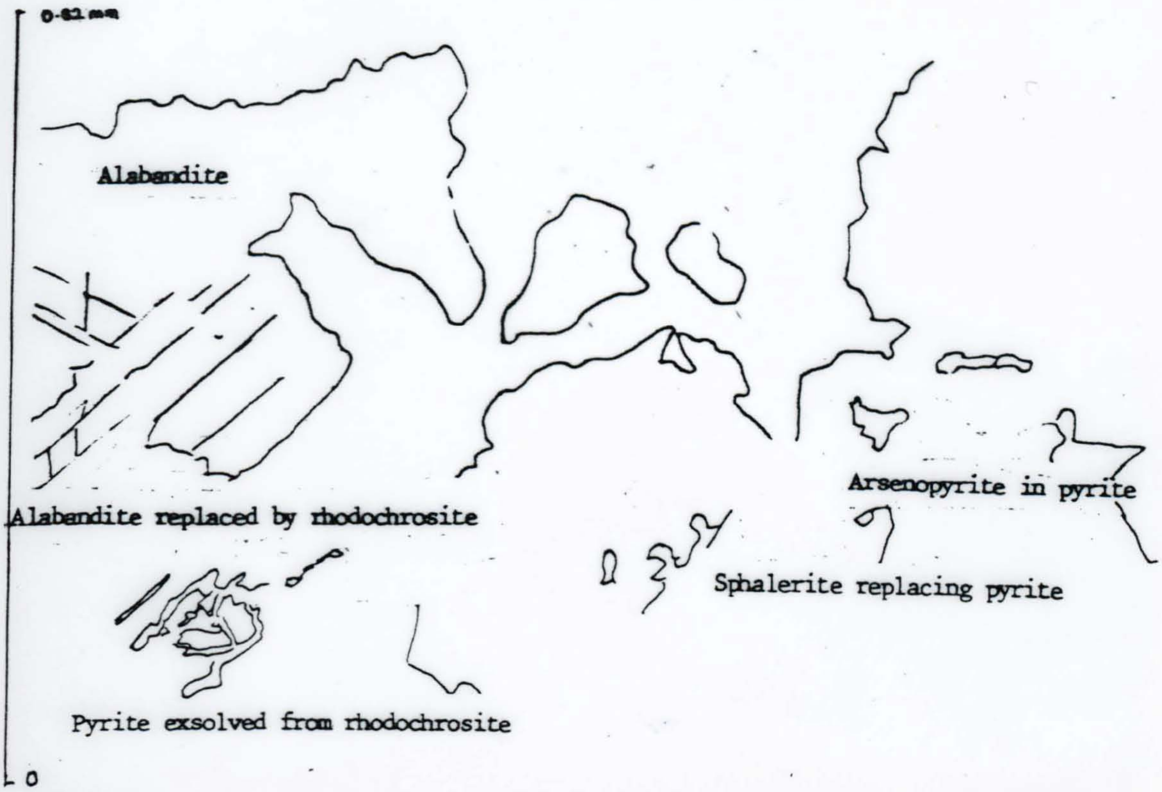
The gangue consists of irregular quartz grains and carbonate overgrown by quartz crystals, as well as quartz in veinlets. Carbonate occurs interstitially to the quartz crystals, and as large patches. Most of the later carbonate was calcite, but some of the earlier carbonate is dolomite or rhodochrosite.

Sulphidic specimens contain sphalerite in early arsenopyrite, within pyrite grains. This sphalerite is possibly not the earliest mineralisation, as sphalerite, chalcopyrite and galena can all be seen replacing pyrite (Plate 14b). Alabandite is present, sometimes replacing pyrite, and itself being replaced by sphalerite or carbonate (Plate 14a). The sphalerite contains both small and larger chalcopyrite inclusions ("chalcopyrite disease"), and is replaced by galena. This suggests an approximate order of deposition of the minerals of:- arsenopyrite, pyrite, alabandite, sphalerite, chalcopyrite, galena, though it is obvious that different sulphides were introduced, and replaced each other at a number of times.

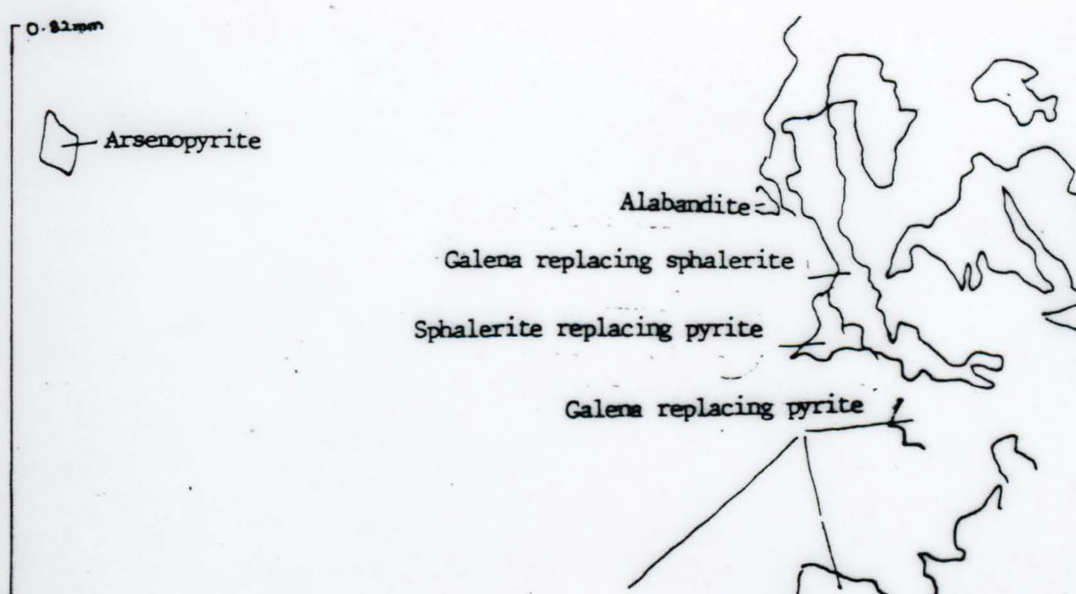
Limited qualitative work with an electron microprobe showed that sphalerite contained some Sn, and Cu, possibly as submicroscopic particles of stannite. Alabandite contained some Sb.

A very extensive description of the Mangani Vein ores

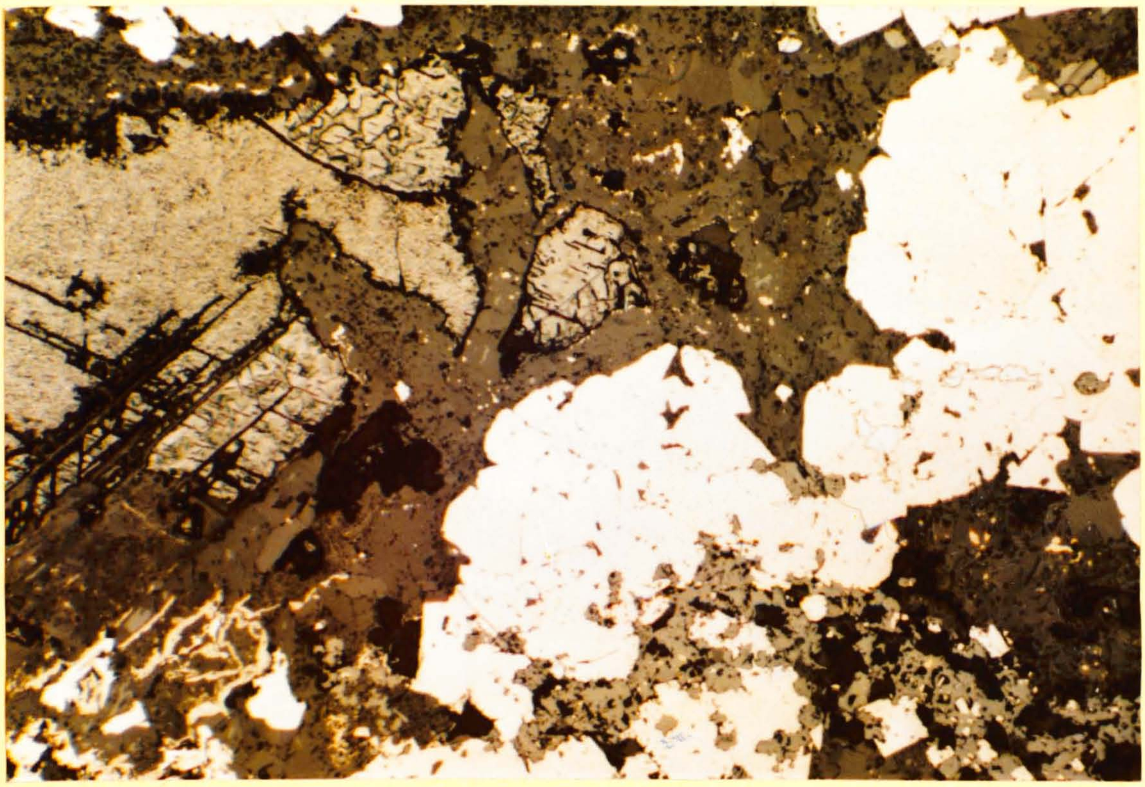
Plate 14



a. Photomicrograph of a polished section of Mangani Vein float (R94a).



b. Photomicrograph of a polished section of Mangani Vein float (R94a).



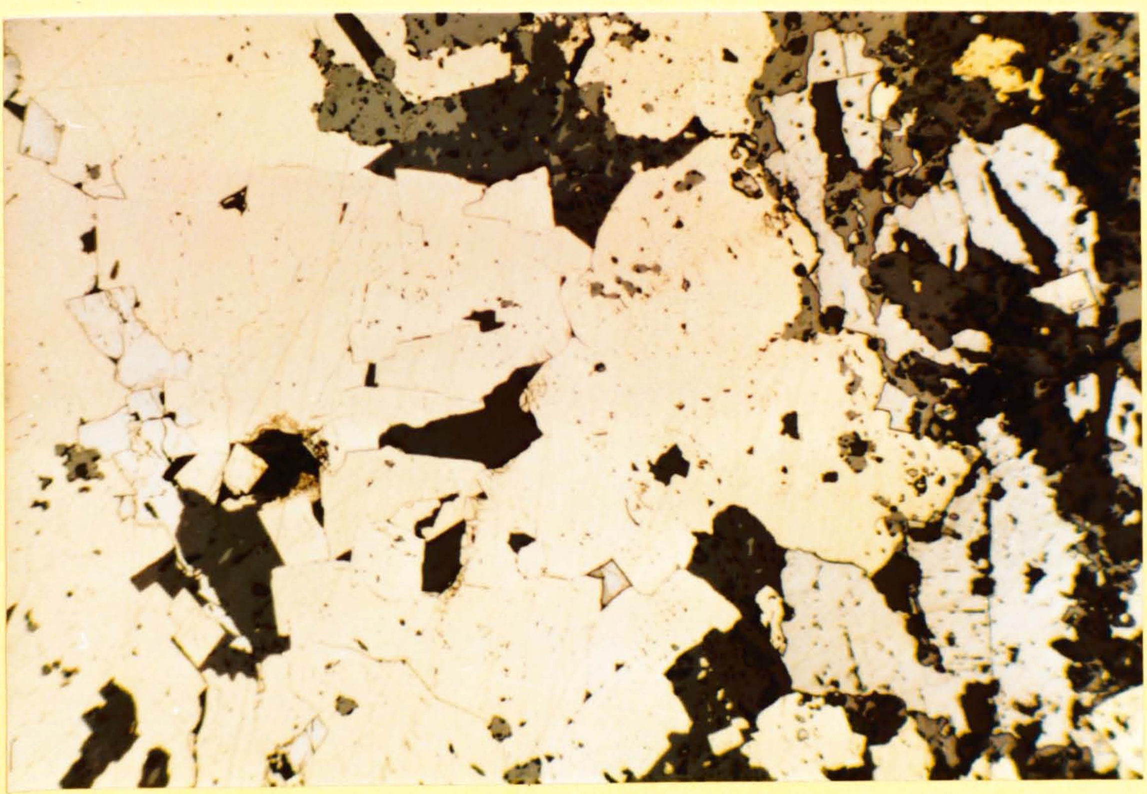
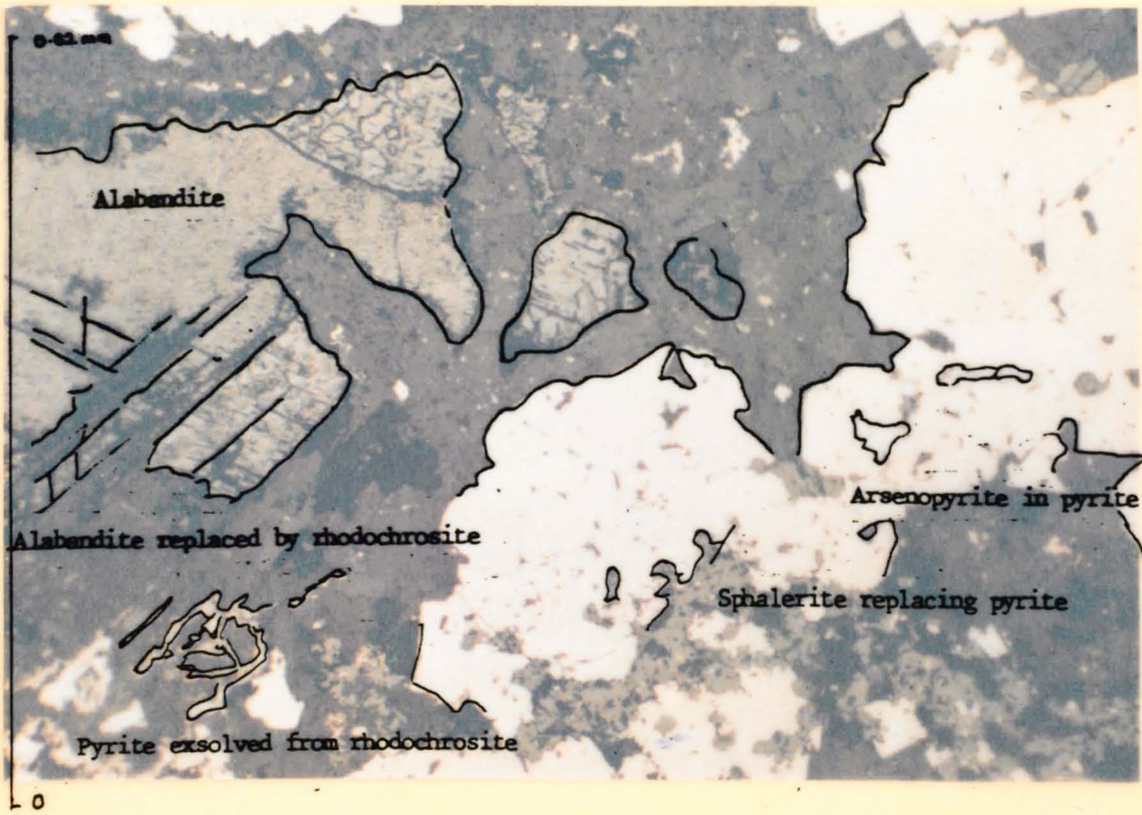
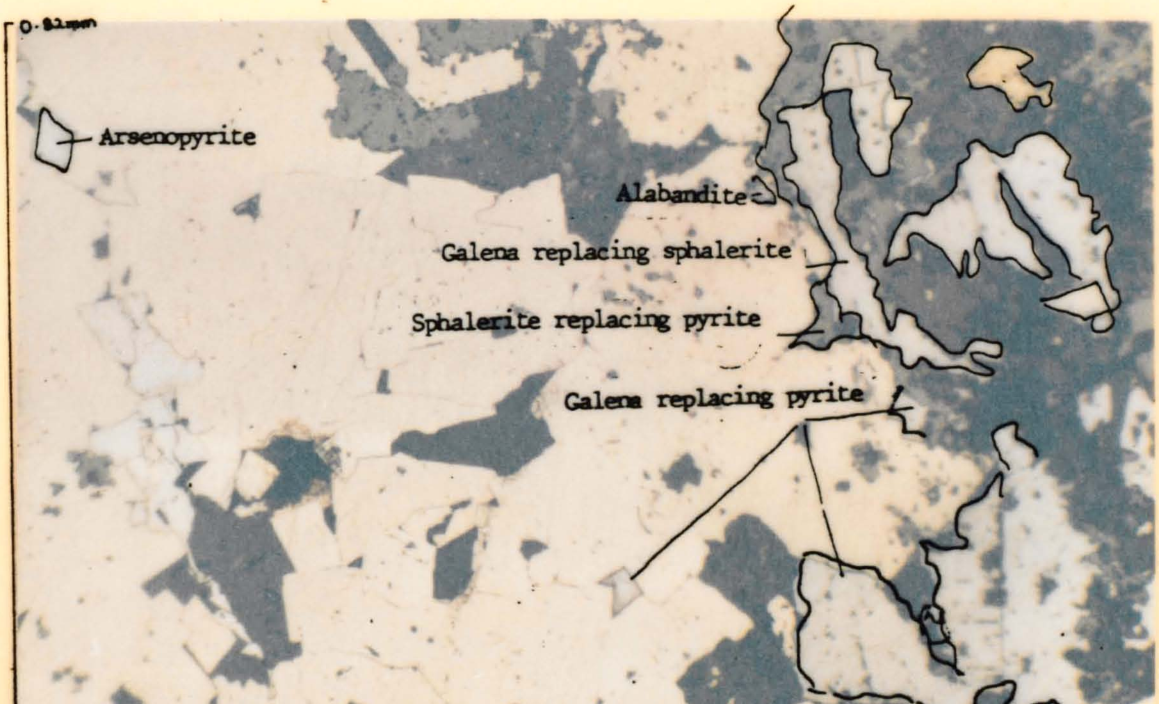


Plate 14



a. Photomicrograph of a polished section of Mangani Vein float (R94a).



b. Photomicrograph of a polished section of Mangani Vein float (R94a).

is contained in De Haan et al. (1933). A limited number of the same samples were rexamined by Kieft and Oen (1974), using a microprobe.

The descriptions in De Haan et al. (1933) suggest that all the vein material still outcropping at Mangani consists of the Old Quartz Vein, with some enrichment by Main Vein mineralisation. All of the more valuable mineralisation has already been excavated. De Haan et al. (1933) state that in less weathered specimens from this vein, collected from deeper in the mine, rock fragments could be identified as propylitised pyritised volcanics.

The sulphidic material examined during the present study of mineralisation at Mangani matches the descriptions of the earliest mineralisation group (A-ore), described by De Haan et al. (1933). In their classification of the ores, the alabandite occurs in the last of the three A-ore groups. Kieft and Oen (1974) suggested that they could also recognise this older ore group, consisting of a distinct Mn-Ag-Sn paragenesis with a quartz and rhodochrosite gangue, with an Ag-Au-Se paragenesis with a quartz and rhodonite gangue comprising the later B-, C-, D-, and E-ores of De Haan et al. (1933).

4.2.8 Geochemical analyses of the Mangani Vein.

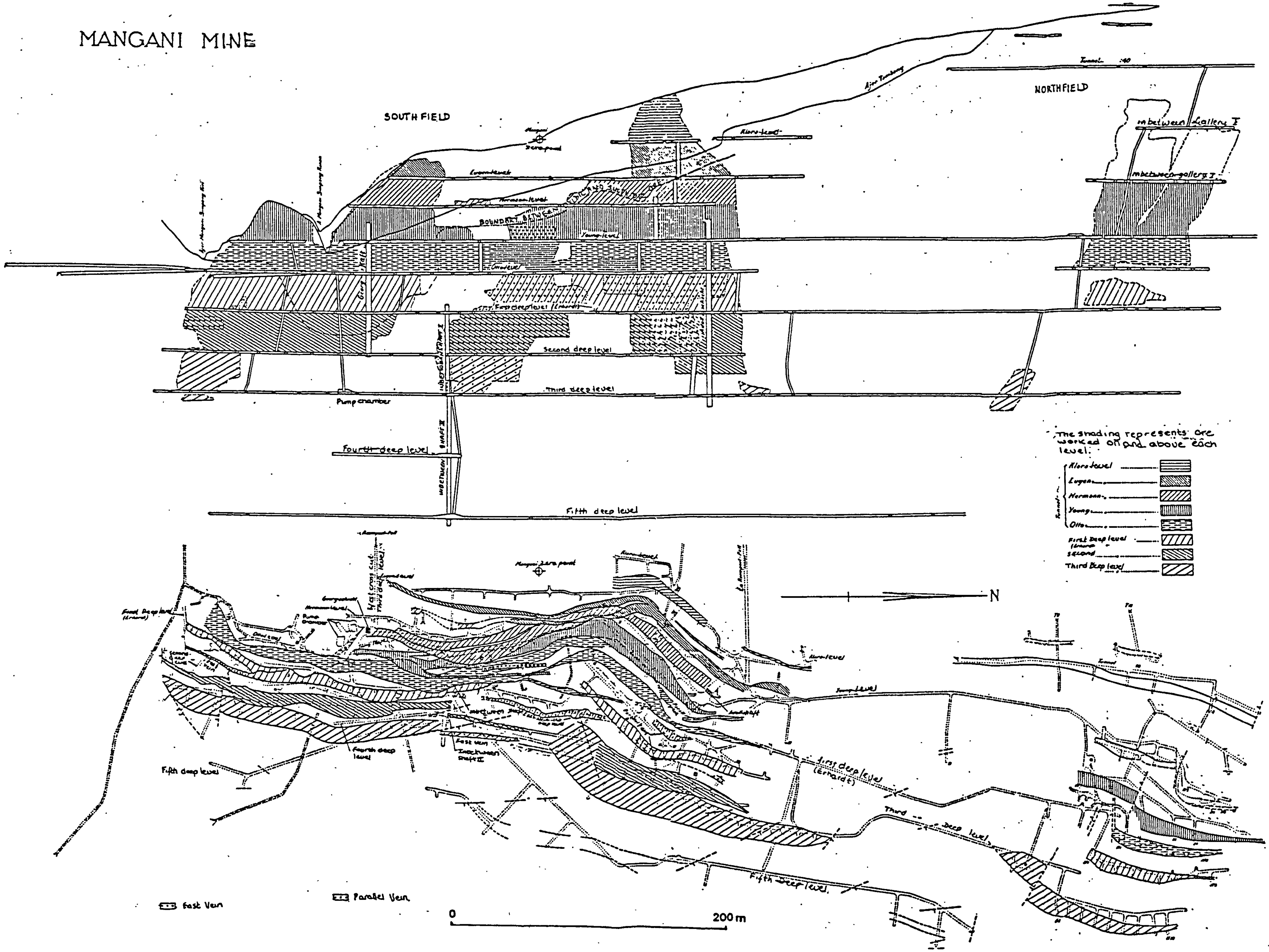
During the present period of research only one channnel sample was collected from a part of the vein exposed to the west of the stream in local workings, as at other localities only the hangingwall of the vein was exposed.

sample	Cu	Pb	Zn	Ni	Co	Cd	Mn	Fe%	Bi	Ag	As	Cr ppm
R584	46	61	140	2	27	2	5.8%	2.16	<0.5	62	220	2

These results illustrate the very high manganese content of the Mangani Vein. Ag, As and Fe are present in moderate amounts, but all other elements analysed are only present in small amounts. Bismuth appears to be absent.

M.M. Aequator annual reports mention many analytical results from particular locations in the mine. These results have been combined with the plan of the

Figure 39. Simplified plan of the Mangani Mine.



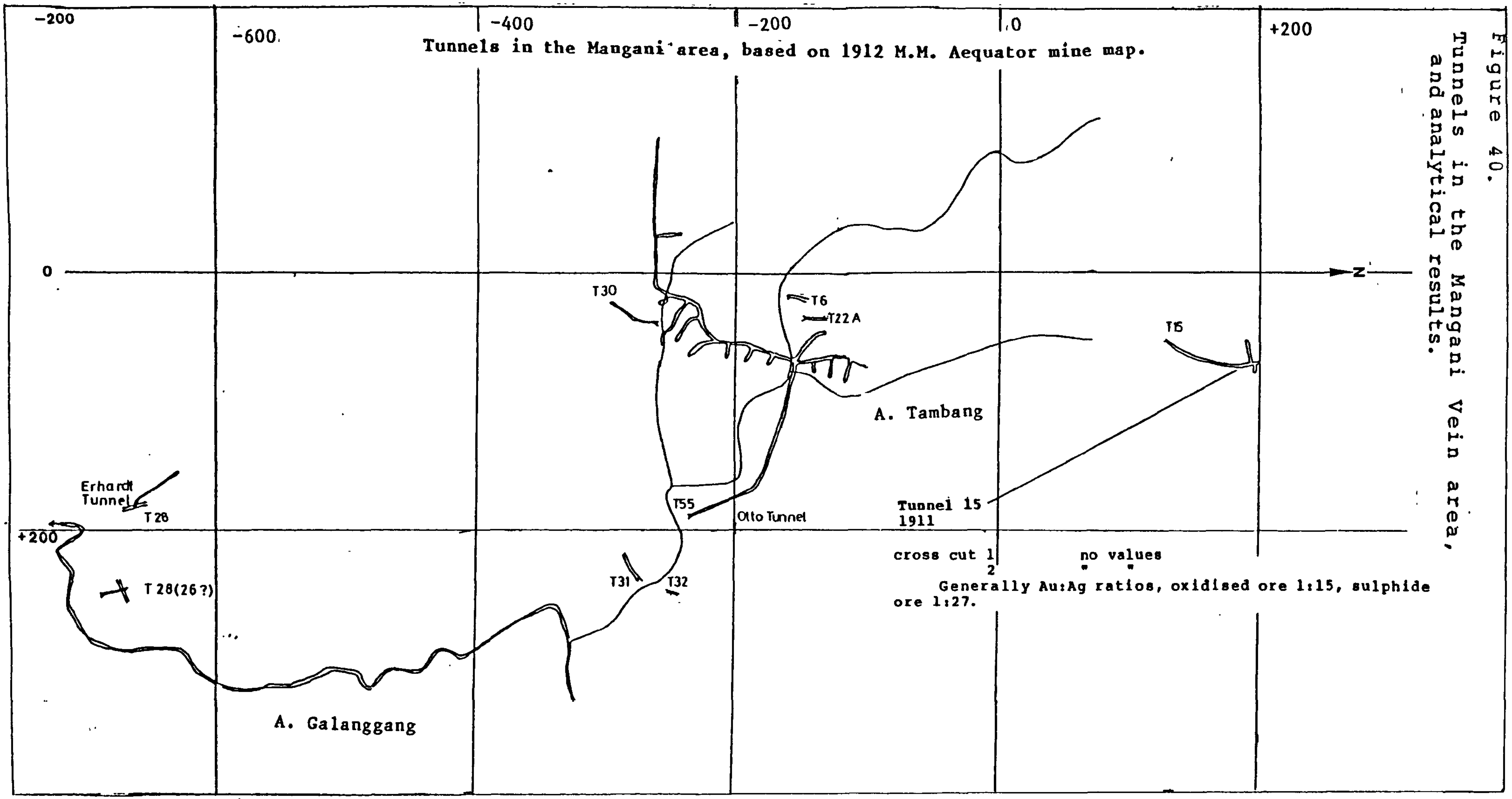


Figure 40. Tunnels in the Mangani Vein area, and analytical results.

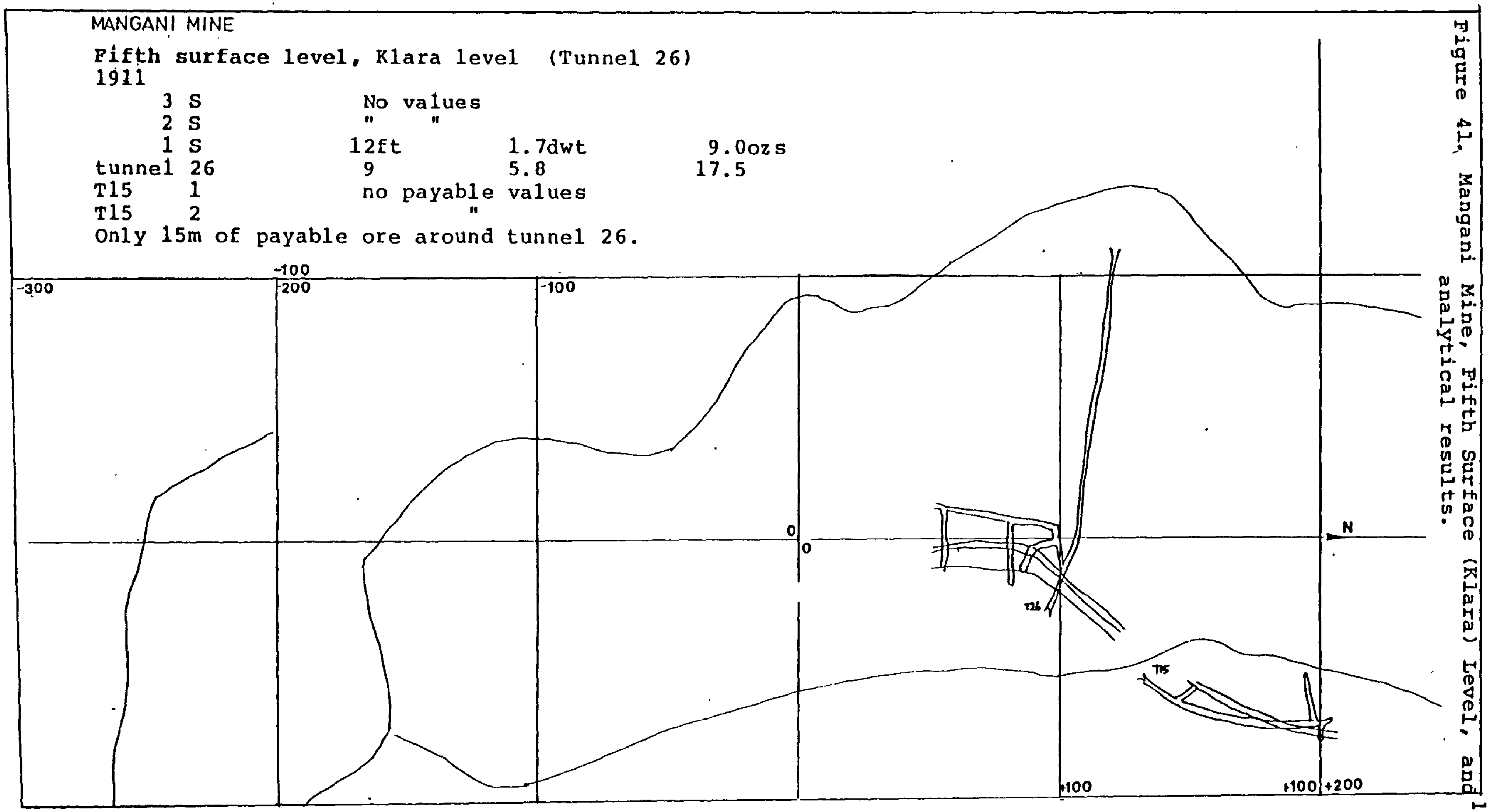
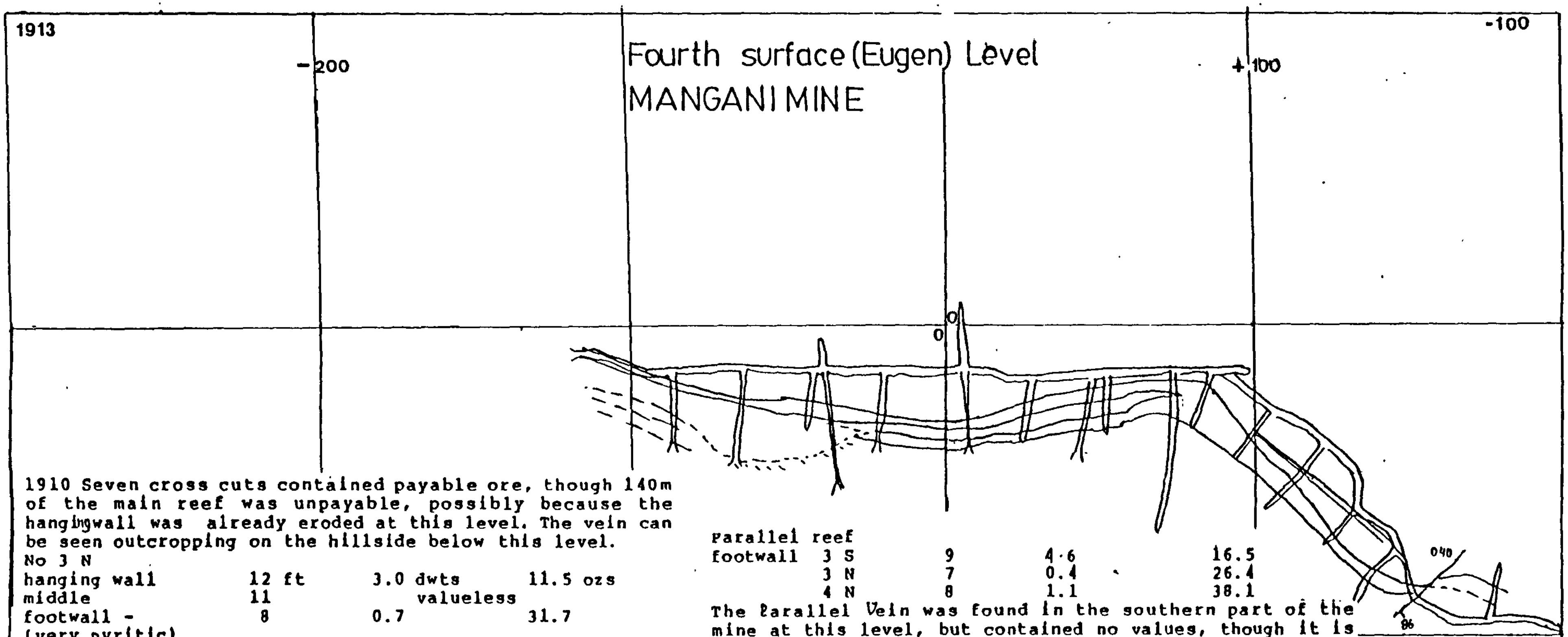


Figure 41. Mangani Mine, Fifth Surface (Klara) Level, and analytical results.



1910 Seven cross cuts contained payable ore, though 140m of the main reef was unpayable, possibly because the hangingwall was already eroded at this level. The vein can be seen outcropping on the hillside below this level.

No 3 N

hanging wall	12 ft	3.0 dwts	11.5 ozs
middle	11	valueless	
footwall - (very pyritic)	8	0.7	31.7

1911

Cross cuts 4S to 2N contained no payable ore

3 N	14ft	12dwt	15ozs
4 N	7	10.7	18.3
5 N	13	2	10
6 N	22	3.2	15.5
7 N	12	12.3	51.3

Cross cut 7 contains primary ore, with a high content of mixed sulphides in a hard well defined vein.

Including values in the Parallel reef, 90m of ore are payable.

Average values	14 ft	5.0 dwts	24 oz

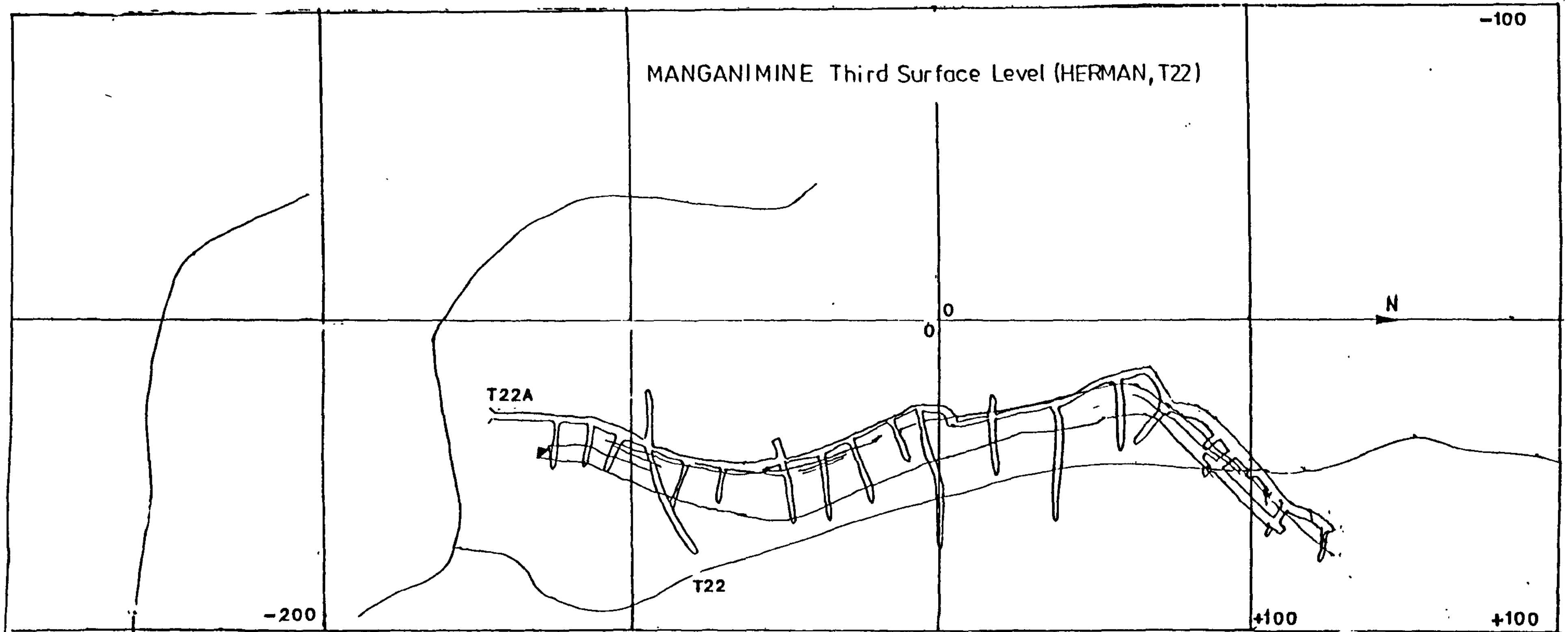
Parallel reef

footwall	3 S	9	4·6	16.5
	3 N	7	0.4	26.4
	4 N	8	1.1	38.1

The Parallel Vein was found in the southern part of the mine at this level, but contained no values, though it is large and well defined. In the northern part the Parallel vein is found in all cross cuts, where it consists of the footwall part of a much wider formation. The two veins separate+have a thin rock layer between them at cross cut 4. In a number of cases a pronounced fault is found in the tunnel at the footwall side of the main vein. This fault becomes larger to the north, and contains fragments of parallel vein material.

The East reef is not seen at this level, as it is already denuded.

Figure 42. Mangani Mine, Fourth Surface (Eugen) Level, and analytical results.



1910 Seven out of 10 crosscuts showed payable ore (80m)

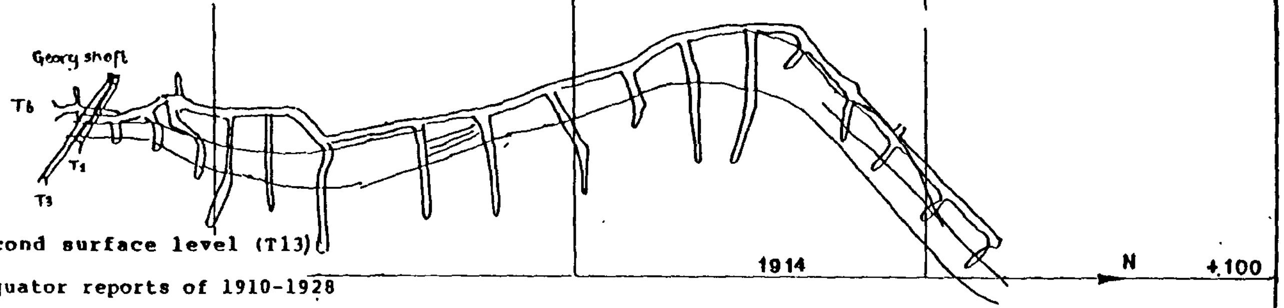
No. 3 cross cut S	10 ft	11.0 dwts	25.0 ozs
2	9	15.7	24.0
1	8.75	15.5	25.0
tunnel 22	13.0	12.0	12.3
no 1 cross cut N	10.25	30.0	38.6
3	4.0	8.4	34.2
4	6	2.7	10.6
5	6	0.5	2.1
5a	6	0.3	10.1
6	6.75	1.7	11.0
7	no values		
8	11.0	3.0	32.4
cross cut 13	5.5m	7dwts	50oz

No 2 cross cut, inrush of mud from hanging wall
7 cross cuts payable, Several more cross cuts in the north are not payable due to absorption of the parallel reef onto the main reef (these are separate in the south). The parallel vein sometimes has good values, but these are erratic, nor is the reef sufficiently definite. As the parallel reef approaches the main reef values become more steady, with more pyrite and ZnS, and rising Ag. The two reefs combine after cross cut 8.
In 1925 65m of new hanging wall gallery had to be built, and a new small very rich veinlet was discovered. Strike NW-SE dip SW
cross cut 8-9 10-12 cm 37g Au 30KgAg
In 1928 gallery 9a to the west was built, but followed a diagonal fault. No ore of importance was found.

Figure 43. Mangani Mine, Third Surface (Herman) Level, and analytical results.

Second surface (Young) Level
MANGANI MINE

Tunnel 1 (T1& T6 are slightly above the Young Level)
1910
1m vein width, 4.25 oz Au 52 oz Ag (over a length of 20m.
Tunnel one continued for a length of 80m, though not with such good analytical results. In the northern part there were good values, though not in the middle.



Young level, Stollen 13, second surface level (T13)

This was mentioned in M.M. Aequator reports of 1910-1928
Main reef
cross cut 6 reef dispersed

western part			
N side upper row	6 ft	0.8dwt	6.3oz
N side lower row	6	8.1	16.5
S side upper row	4	1.1	5.4
S side lower row	4	2.0	3.6
Average	5	2.7	11.2
Eastern part			
N side upper	4	1.0	12.7
lower	4	1.0	25.6
S upper	4	0.0	9.9
S lower	4	0.0	11.0
Average	4	0.7	14.8

tunnel 13	12ft	30.6dwt	34.1oz
cross cut 1 N	13	16.7	13.2
2	5.5	10.6	12.5
3	9.5	11.8	21.6
4	9.25	14.3	23.6
5	7.75	11.5	14.0
6	5.0	2.7	11.2
7	3.0	2.7	5.0
8	3.0	9.5	20.0
9,	3.0	3.0	11.4

cross cut 15	7.5m	10.32dwts	82oz
16	2.4M	5	20

In 1915 The Young Level was extended 154m beyond the northern edge of the ore shoot, and found the northern part of the Mangani main vein. Both the main and parallel vein were worthless.
In 1921 a tunnel into the vein was cut from the west bank of the A. Mangani Kanan (A.Tambang)

3m	22g Au	937g Ag

East Vein
Several cross cuts show the east reef further to the east. This is first seen in cross cut 4, after the black oxidised main reef is passed, where there is a thickness of red material containing a significant amount of manganese, and the dark pyritic leader vein. The leader vein is thin, but locally contains up to 200 oz Ag. In cross cuts further to the north the east vein separates completely from the main vein.

cross cut 6 N	4.0ft	0.7dwt	14.8oz
7	4	9.5	30.6
8	3	0.1	3.5
10 E	1.25m	0.9g	198g

In 1921 the East vein was followed north from cross cut 10 but proved worthless. In subsequent years it was followed as far as cross cut 16, but no good ore was found. Between cross cuts 10 and 11 a 4m section had 1g Au and 1068g Ag per ton. Between cross cut 17 and 18 a trial cross cut was extended for a few metres, though without result.

West Vein
Rich small veinlet to the west of the known mineralisation found in cross cut 11, 12 in 1926 containing
3g Au 2508g Ag
a long cross cut was built to Rumput Pait between 1926 and 1928. At one point problems with water seepage occurred, possibly coming from the A. Mangani Kanan, via the west vein fracture. When the vein was reached it had poor values, with poor rock, and problems with water. This is generally true of the hanging wall of Rumput Pait.

Figure 44. Mangani Mine, Second Surface (Young) Level, and analytical results.

Figure 45. Mangani Mine, First Surface (Otto) Level, and analytical results.

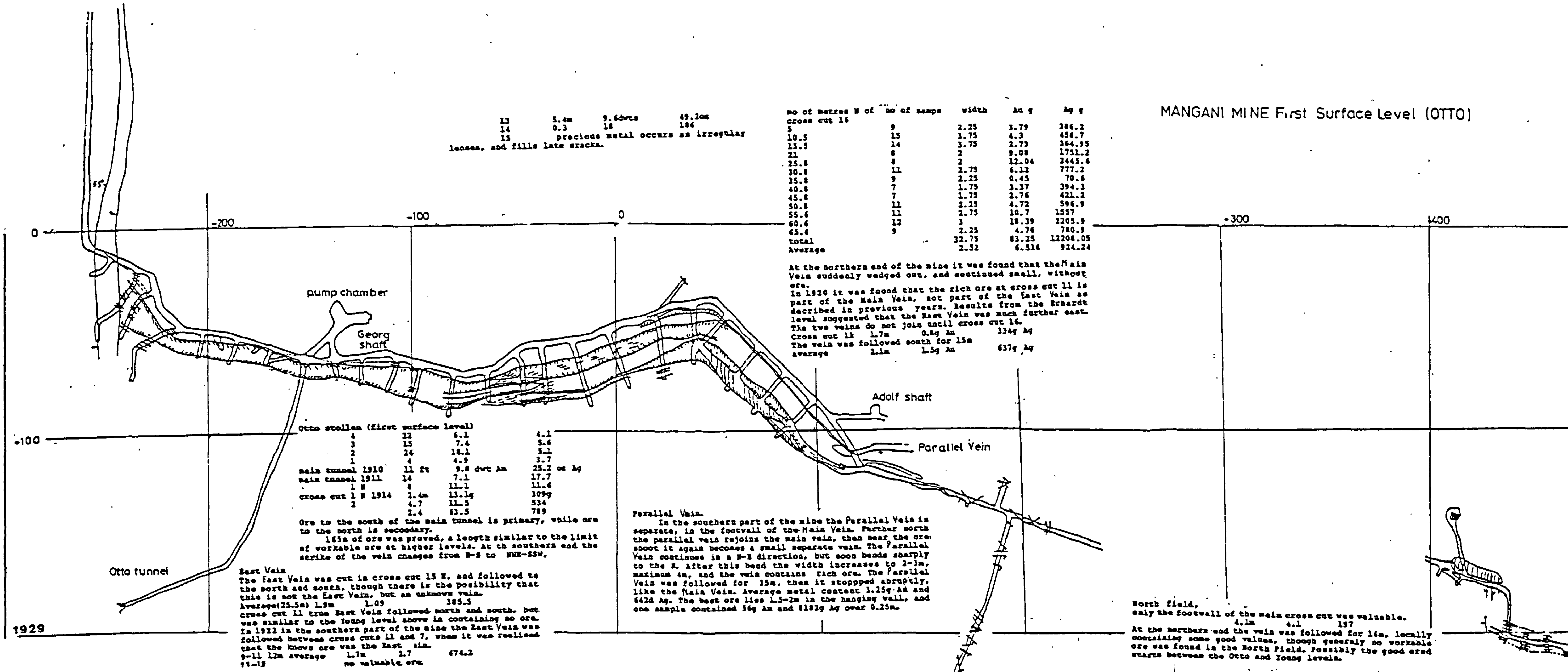


Figure 46. Mangani Mine, First Deep (Erhardt) Level, Second Deep (Grammel) Level, and analytical results.

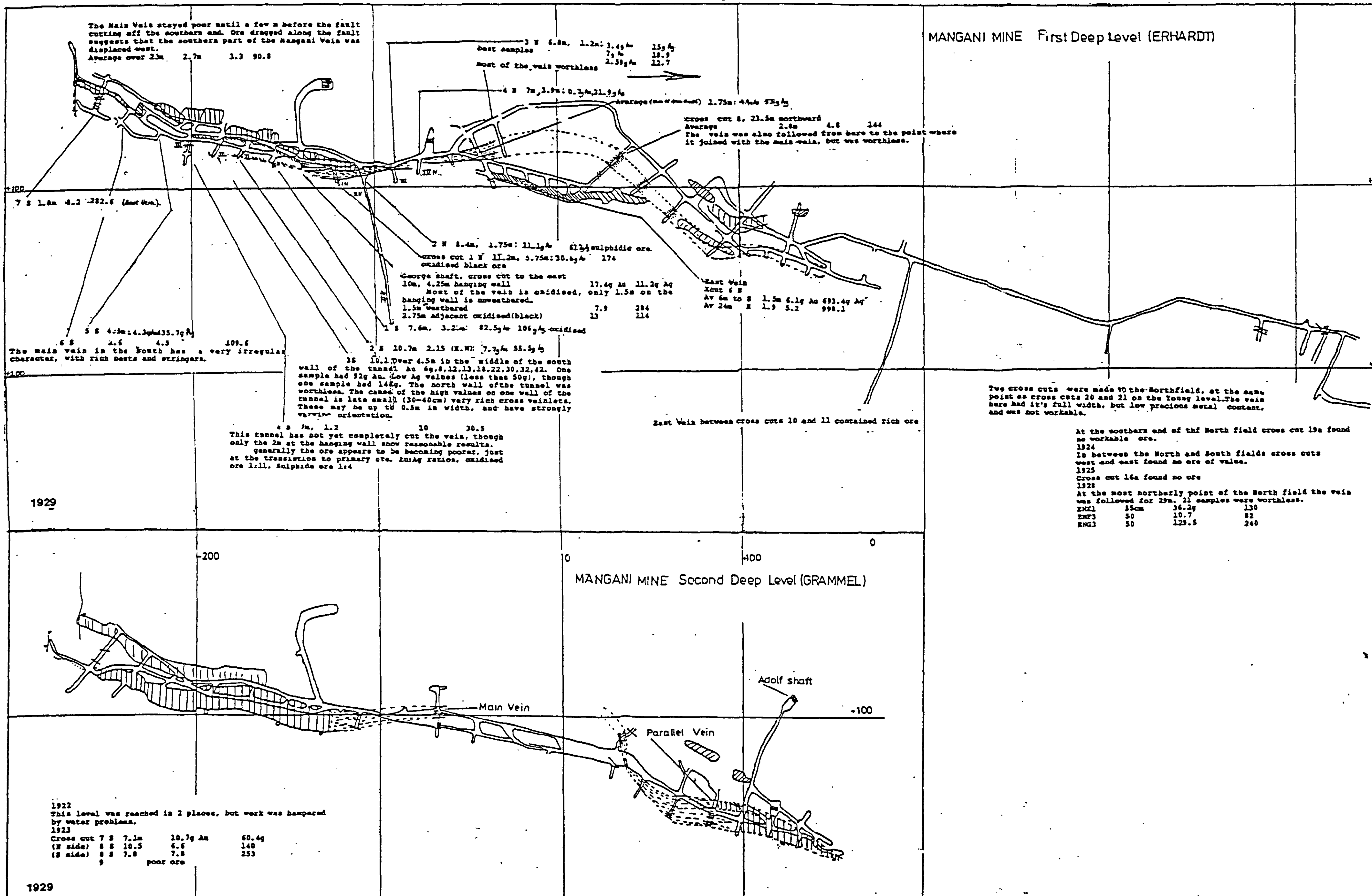
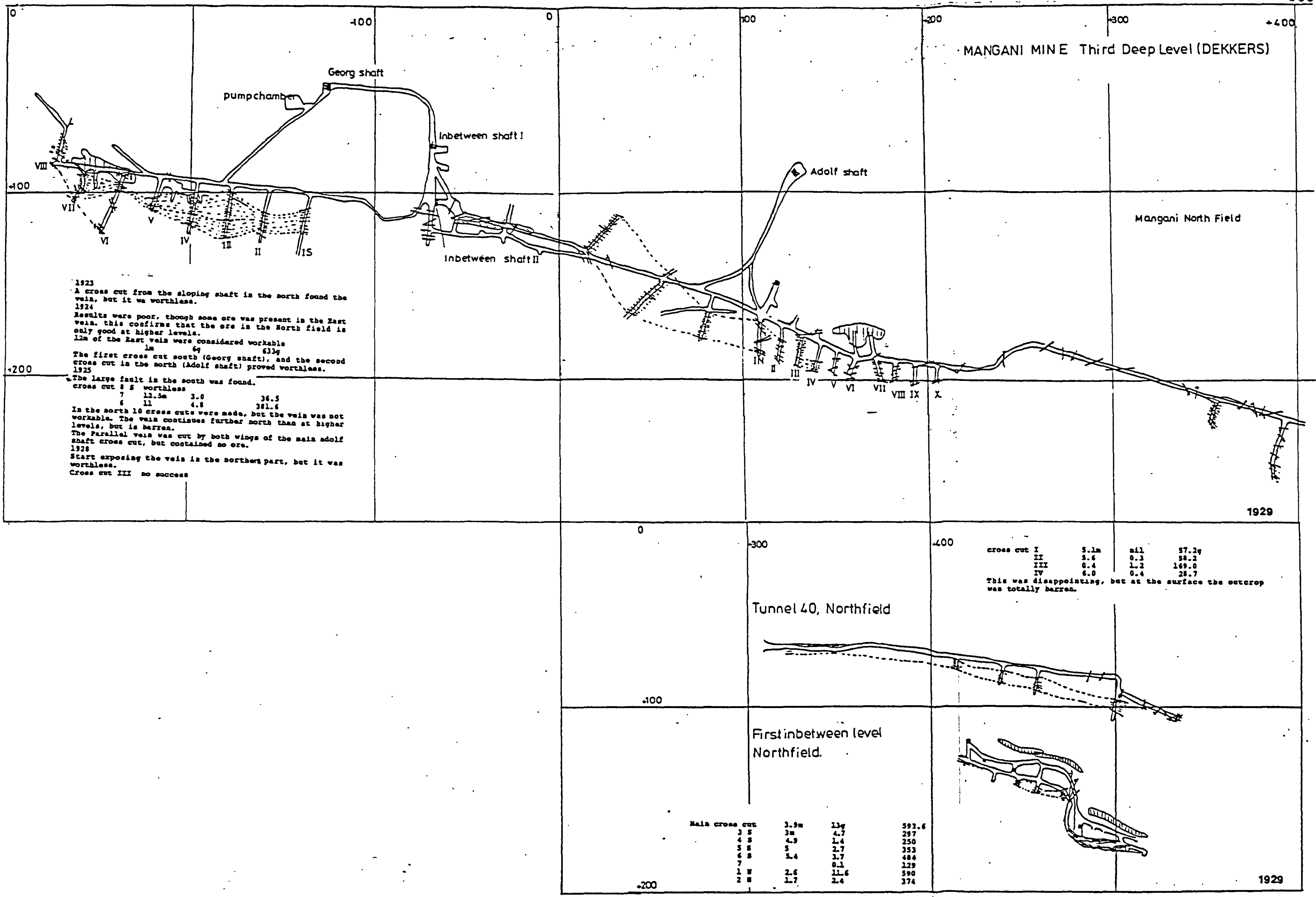


Figure 47. Mangani Mine, Third Deep (Dekkers) Level, Tunnel 40 - North Field, First Inbetween Level and analytical results.



appropriate level in Figures 40-47, giving an indication of the distribution of precious metal and vein size in the mine. In some cases the total vein width, and the width sampled are both shown, otherwise the width refers to the sample width. These plans show that ore shoots can be recognised, but that low values occur in these areas, and large values occur outside the areas.

4.3 The Rumput Pait Vein

4.3.1 Introduction.

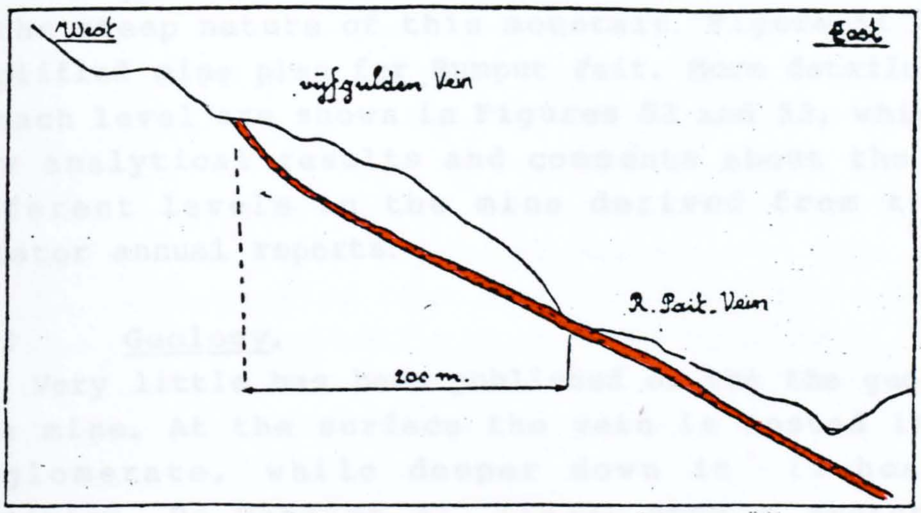
The area around the Rumput Pait Vein was first investigated during 1906-1909, when quartz vein outcrop with low gold values was found on the B. Kulit Manis ridge. Only in 1922, when two prospectors were taking a short cut home, was a richer part of this vein discovered. This is again evidence that initially dissappointing vein outcrops may be part of a richer zone, and since at Mangani only small parts of each vein are exposed, the possibility of missing a valuable mineral vein is high. Exploitation of the vein started in 1922, and ceased in 1931. Initially the 5 Gulden (5 Guilder), and Zestig Meter (60m) Veins were thought to be separate mineral occurrences, but it was later realised that these are part of the Rumput Pait Vein, and occur as separate outcrops because the Rumput Pait Vein locally dips at a shallower angle than the hillside.

During the present investigation the outcrop of this vein at the entrance of 3 adits on the southern side of the B. Kulit Manis ridge was investigated, but the adits were not entered. Local people call the vein at this point the Kulit Manis Vein, but on the map published in De Haan et al. (1933), this is marked further to the west.

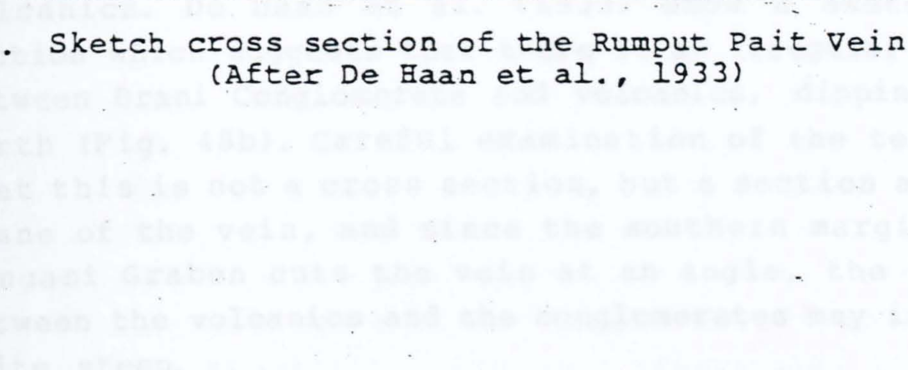
4.3.2 Details of the mine.

Levels were spaced at 25m, and numbered downwards in ones from a base level of 0, and upwards in 10s. RP 8 is at the same topographic height as the Young Level of the Mangani mine. The Teuffel Level at Mangani was opened up using the Rumput Pait shaft. Many of the levels reach

Figure 48



a. Sketch cross section of the Rumput Pait Vein
(After De Haan et al., 1933)



b. Geological sketch map along the Rumput Pait Vein
(Modified after De Haan et al., 1933)

both the north and south slopes of the B. Kulit Manis due to the steep nature of this mountain. Figure 51 shows a simplified mine plan for Rumput Pait. More detailed plans of each level are shown in Figures 52 and 53, which also show analytical results and comments about the ore at different levels in the mine derived from the M.M. Aequator annual reports.

4.3.3 Geology.

Very little has been published on the the geology of this mine. At the surface the vein is hosted in Brani Conglomerate, while deeper down it is hosted in volcanics. De Haan et al. (1933) show a sketch cross section which suggests that there is an irregular boundary between Brani Conglomerate and volcanics, dipping to the north (Fig. 48b). Careful examination of the text shows that this is not a cross section, but a section along the plane of the vein, and since the southern margin of the Mangani Graben cuts the vein at an angle, the boundary between the volcanics and the conglomerates may in fact be quite steep.

To the north De Haan et al. (1933) report Telisa Formation shales above RP 4, and these occur further to the south in the deeper parts of the mine.

4.3.4 Structure.

On the south side of the B. Kulit Manis ridge, the vein orientation is 015/42^{o}E, and according to De Haan et al. (1933) this is the overall orientation, though the dip and strike show a lot of variation. At the surface this vein is 600m from the Mangani Vein, while at the deeper levels the veins are only 400m apart.

De Haan et al. (1933) state that at its southern end the vein turns in a NE/SW direction until it is cut by the fault. At that point the vein is small (1.5m), and not workable.

At the northern end the quartz vein is sharply truncated by the Egert Vein/Zone. North of this fault a small quartz vein (1m) with locally high values is reported as becoming poorer, and breaking up into small veinlets when it reaches the Telisa Formation sediments.

In the mine the vein is described as being affected by two main fault directions.

1/ Faults parallel and diagonal to the vein, sometimes with horizontal or inclined slickensides, result in many small clay bands parallel to the vein. These structures suggest that the vein formed in a fault zone, with continual faulting and deposition of minerals. In the discussion of the structure of the Mangani area (Chapter 2), it was suggested that the N/S oriented fractures at Mangani, which initially formed as tensional features, could later have acted as dextral fault zones, a conclusion supported by this evidence.

2/ 095° trending cross faults are described offsetting the main vein, as well as the small quartz vein north of the Egert Zone. These faults displace the vein for only a few metres, but are common. The largest movement can be seen on the plan of RP 1 (Fig. 53). In some cases these faults are described as having been formed after the formation of the quartz vein, but before the mineralisation. In the interpretation of the structure of the Mangani area as a whole (Chapter 2), it was suggested that antithetic faults with this orientation formed as a result of the later stress pattern in the area. The offsets of the vein shown on the mine map are sinistral, which is in agreement with this interpretation.

Below the RP 20 level, mine plans show that the vein bends. Downward this flexure becomes less pronounced, but generally the axis of the flexure plunges to 135°. This bend may have formed as a result of dextral NW/SE fault movement, but the vein is described as being unbroken, suggesting that the vein formed at the same time as the fault movement.

4.3.5 Vein width.

At the point where the vein was found outcropping, the quartz vein was about 7m thick. The average thickness worked was 1-2m , but this varied greatly.

4.3.6 Petrology.

The outcrop of this vein investigated during the present study is hosted in the Brani Conglomerate (Fig. 49), and consists of massive and banded quartz, with a low sulphide content. Figure 49 is a sketch of the vein outcrop investigated, and shows the locations of samples.

Most specimens proved to be highly weathered, only occasionally containing recognisable pyrite. The vein material consists of fine interlocking quartz grains with abundant dusty inclusions, replaced and veined by later quartz crystals. Haematitic patches and veinlets are presumably the alteration product of pyrite. In some cases the early patchy quartz looks as though it may be the result of extreme alteration of the host rock. Fluid inclusions occur in both the early and later quartz, usually irregular in shape and size. In some cases gas bubbles are present. In some specimens the remains of clasts can be recognised, either by the differing grain size, which can be either larger or much smaller than the matrix, or in some cases clasts appear to consist of quartzite, cemented by later quartz. The variation in the grain size of the clasts suggests that these may be the remains of clasts from the Brani Conglomerate, rather than altered tuffaceous material.

4.3.7 Analytical results.

7 channel samples were collected during the present investigation from the entrance of three adits to the south of the B. Kulit Manis ridge. Figure 49 shows the sample locations, and the analytical results are shown in Figure 50.

These analytical results presented in Figure 50 suggest that De Haan's description of mineralisation south of the bend in the vein being low in sulphides is correct. These samples can be categorised as low pyrite and base metal sulphides, low Mn, Sn and Bi, and high Ag, As and Sb. Ni and Cr are very low, but Co is quite high. Gold is present in some of these samples.

Generally these results can be divided into groups, with Co, Fe, Pb, Cu and As having a similar distribution for the channel samples, as well as Mn, Zn and Ag. The grab samples collected from the second adit show a slightly different picture, with Ag and As having a similar distribution, while Mn and Au have the same pattern. Cu, Pb, Zn and Sb can also be grouped together. A conspicous factor is the lack of correlation between Ag and Au, Au being mainly correlated with Mn.

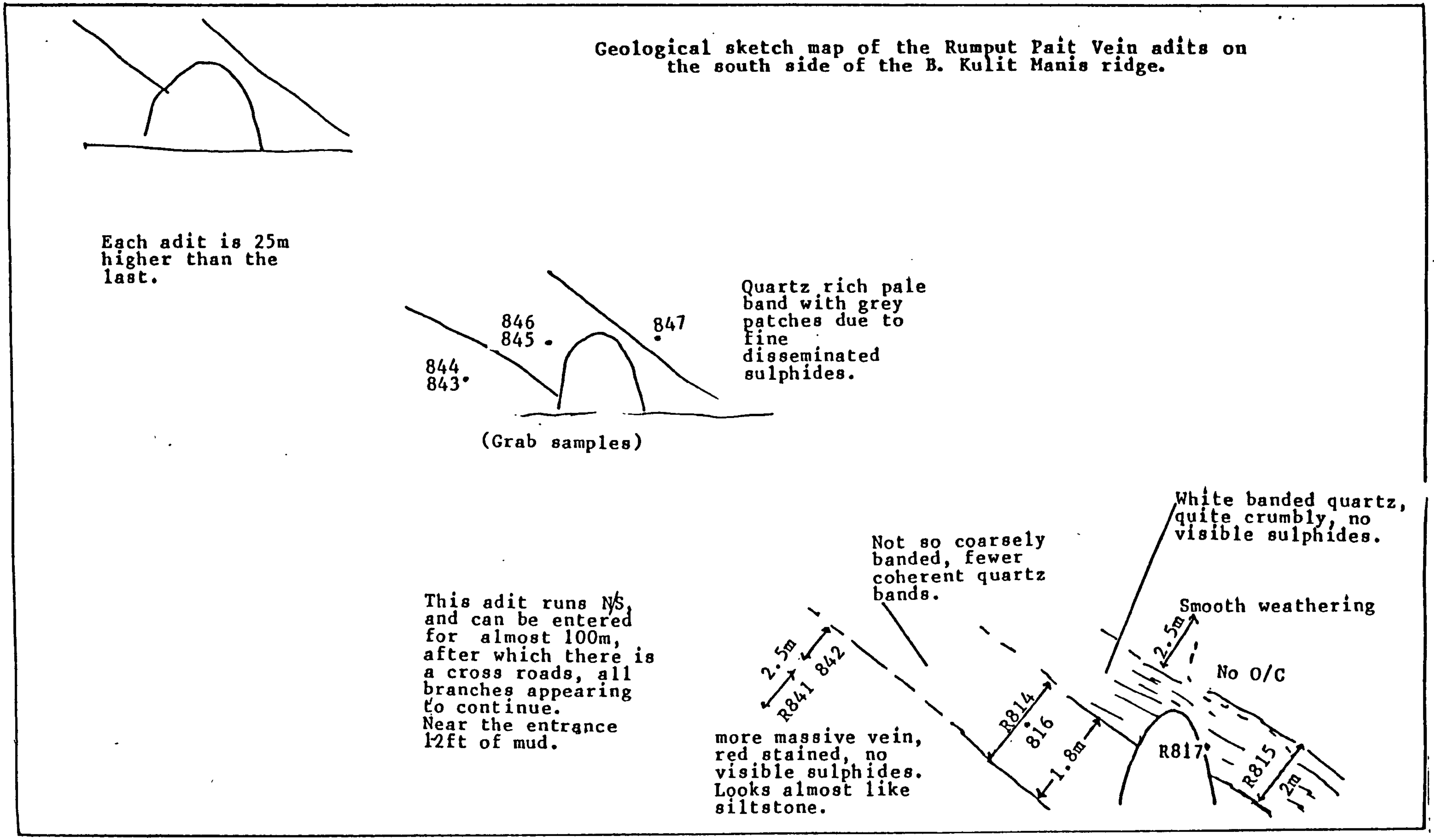
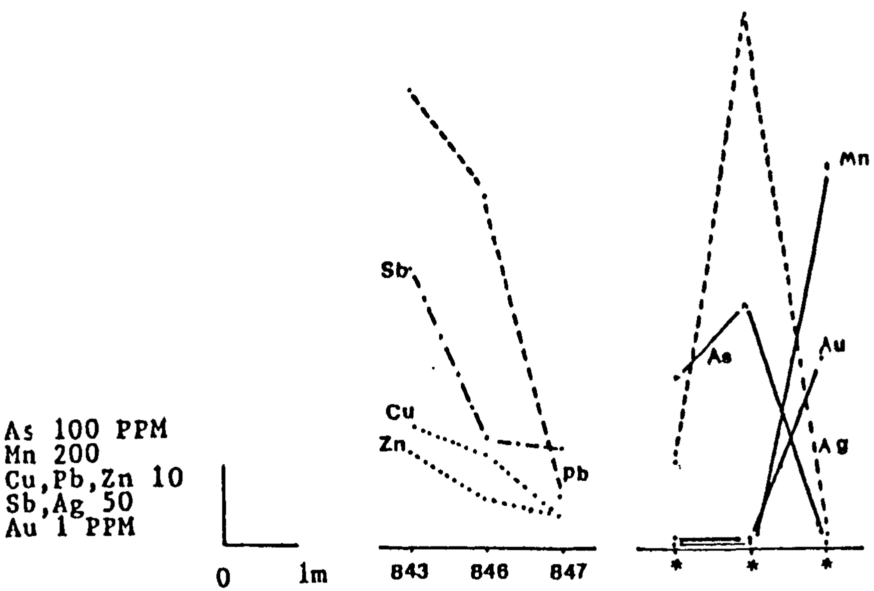
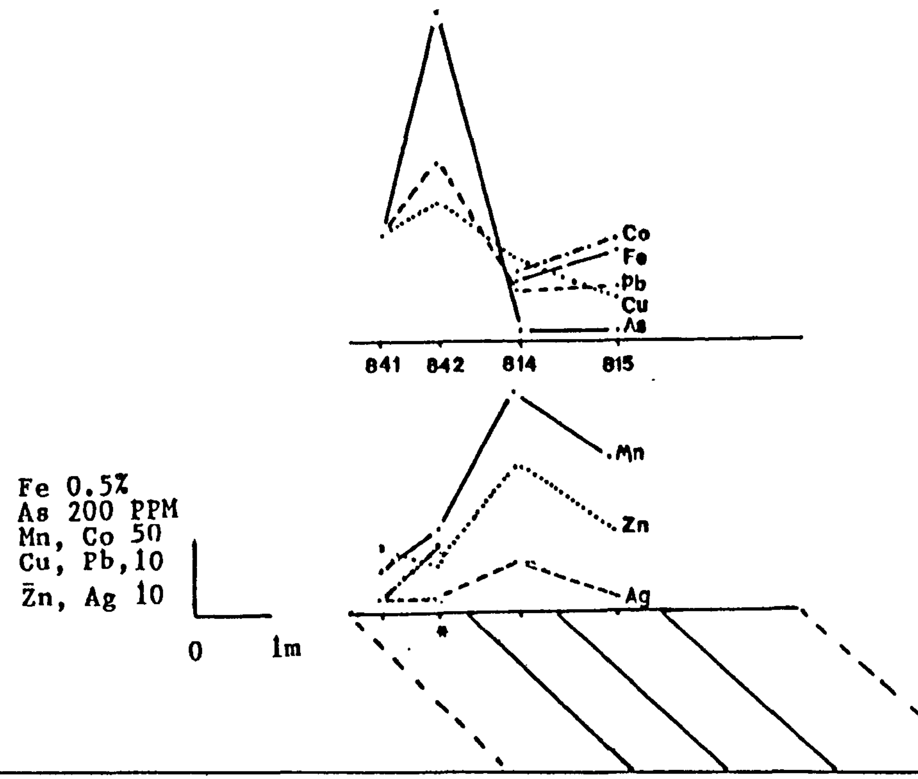


Figure 49. Sketch of the Rumput Pait vein adits on the south side of the B. Kulit Manis ridge, and location of samples.

Analytical results from the Rumput Pait Vein adits on the south side of the B. Kulit Manis ridge





Sample	Cu	Pb	Zn	Ni	Co	Cd	Mn	Fe%	Bi	Ag	As	Cr
Ma R814	11	9	19	1	46	1	143	0.38	-0.05	6	28	1
815	7	7	11	1	67	-1	106	0.58	-0.05	2	30	1

	Cu	Pb	Zn	Sn	Mn	Sb	Au*	Ag	As
841	14	14	8	6	28	8	-0.05	2	280
842	18	24	6	4	55	44	1.40	2	870
843	16	60	12	-4	44	185	0.15	60	230
846	12	46	6	-4	65	70	0.15	360	330
847	4	6	4	-4	1000	65	2.5	10	14

Figure 50. Analytical results from the Rumput Pait Vein.

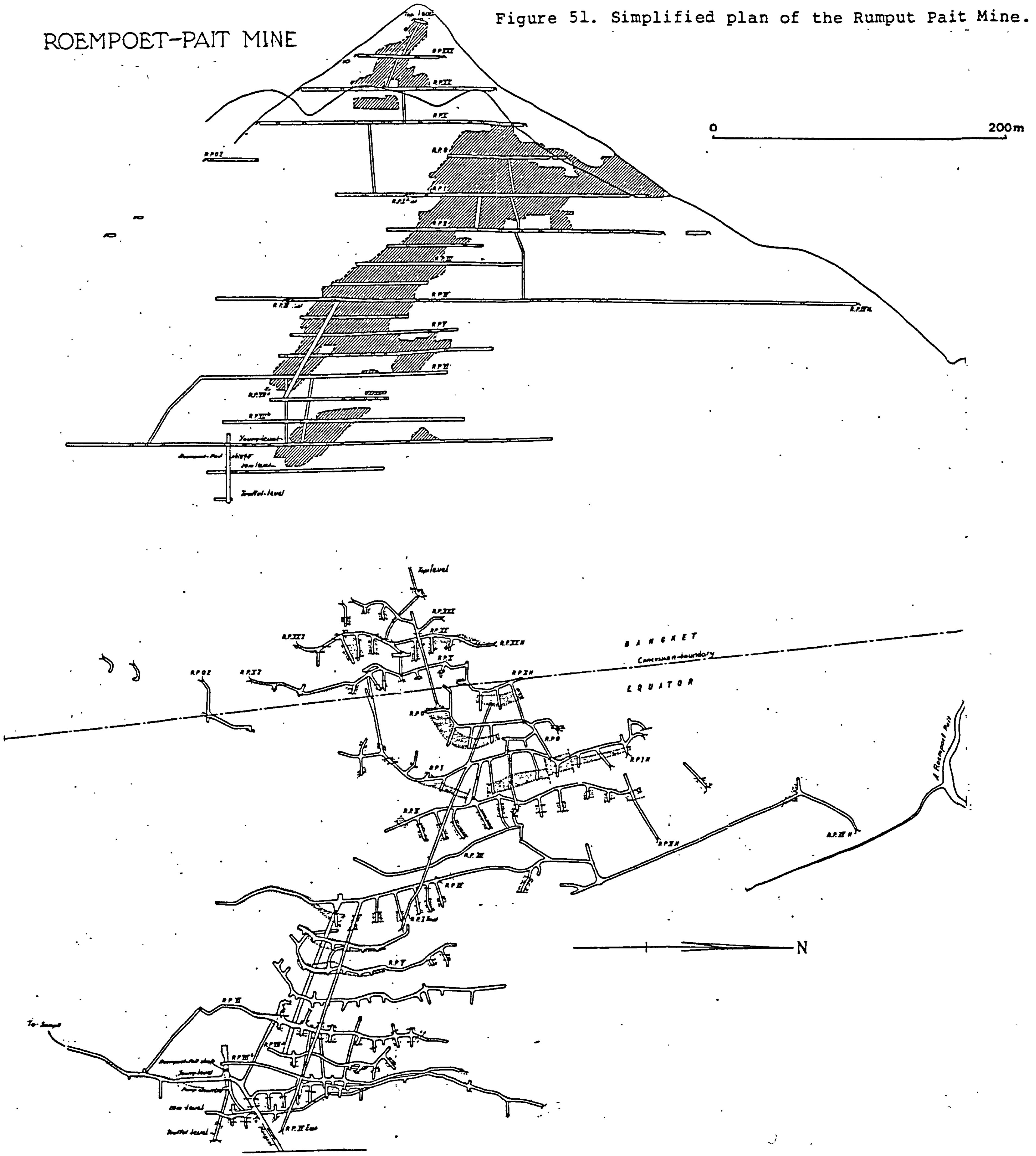
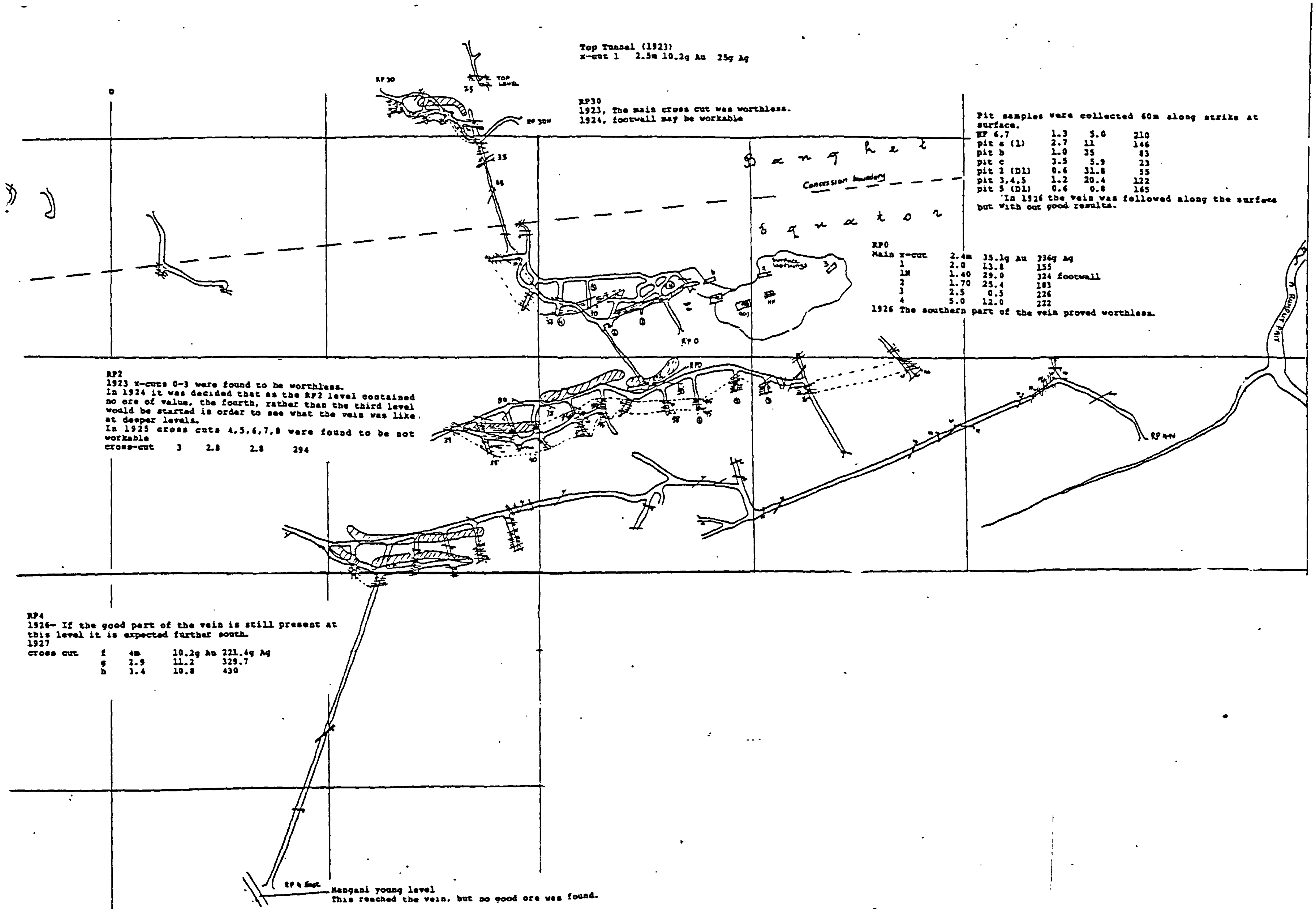


Figure 51. Simplified plan of the Rumput Pait Mine.

Figure 52. Rumput Pait Mine, Top Tunnel, RP30, RP0, RP4, and analytical results.



RP10

Main X-cut	2.4m	12.4g Au	119g Ag
1	3.7	7.7	139
2		2.3	11

In 1924 cross cuts 3,4,5,6,7 were found to contain no appreciable ore.
1925: The vein is well defined from the outcrop in the south, but contains little ore.

Tunnel 5A (Vijf Gulden: 5 guilder Vein)
X-Cut 0 worthless.

RP20

The gallery was found to be worthless in 1923.

cross cut	1	very thin	5.4g Au	11g Ag
	2	"	3.7	20
footwall	3	2.6m	9.7	27
gallery, footwall		1.4	6.1	33
	4	2.5	11.6	36
	5	4.9	6.6	16
	6	7.5m	5.1	11
	7		worthless	

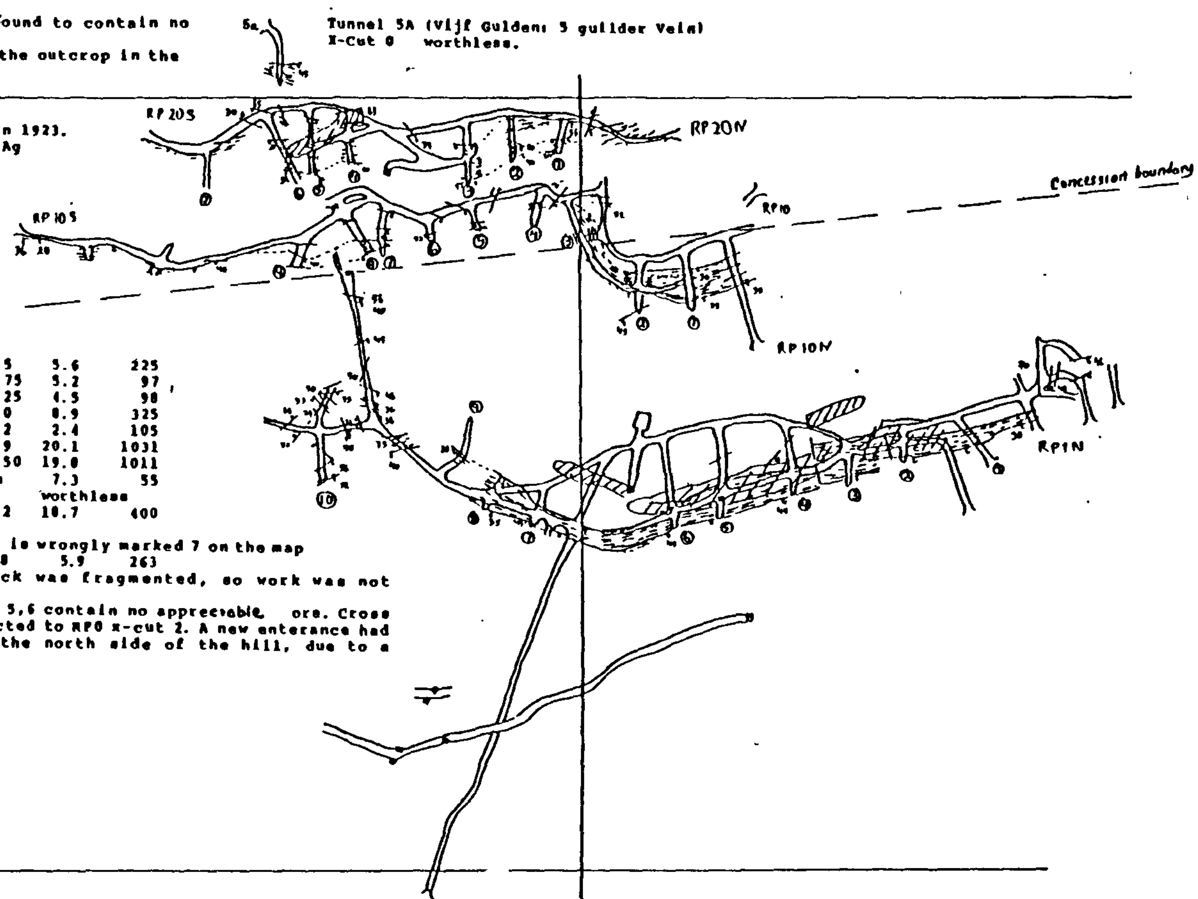
The footwall gallery was built to the south side of the hill.

RP1 X-cut	0	1.5	5.6	225
1922	1 S	1.75	5.2	97
	2	2.25	4.5	98
	3	5.0	8.9	325
	4	4.2	2.4	105
	5	5.9	20.1	1031
	6	3.50	19.8	1011
cross cut	5 S	5m	7.3	55
	6		worthless	
Drainage tunnel	2		18.7	400

1924 cross cut 0 is wrongly marked 7 on the map

X-cut	7	2.8	5.9	263

9,10,11 the rock was fragmented, so work was not possible
1925 cross cuts 5,6 contain no appreciable ore. Cross cut 5 was connected to RP0 x-cut 2. A new enterance had to be made on the north side of the hill, due to a landslide.



① Cross cut number

Figure 53. Rumput Pait Mine, T5a, RP20, RP10, RP1, and analytical results.

Analytical results mentioned in the M.M. Aequator annual reports are shown together with the map of the appropriate level in Figures 52 and 53. These figures give some idea of the distribution of the precious metals, and the vein widths.

The location of the following sample collected by CSR Ltd is not known, but generally the analytical results are similar to those shown in Figure 50. The low Mo content is similar to that found in other samples where this element has been analysed, suggesting that these veins are not related to a porphyry copper deposit.

Sample	Au	Ag	Cu	Pb	Zn	As	Bi	Mn	Mo ppm
A99653	1.4	17.1	13	5	7	470	0.5	58	4
	2.37	15.4							

4.3.8 Au:Ag ratio

The ratio of 1:29.7 is derived from De Haan et al. (1933), rather than the analytical results available in this text, as they had access to analytical results from a larger area.

4.4 The Vijfgulden Vein (5 guilder)

This vein was found in 1922, and followed for 175m along strike.

Av	1m	2.5g Au	21.6g Ag

Later it was realised that this was part of the Rumput Pait Vein (Fig 48a).

4.5 The Kulit Manis Vein

4.5.1 Introduction

During the present period of research this vein could not be located. Local villagers when asked to take someone to the Kulit Manis Vein, guide people to a place where three adits into the Rumput Pait vein are located (Fig 49). The area in which the vein is marked on various maps was examined, but the steep nature of the terrain and heavy undergrowth may have obscured the adits and outcrop.

This vein was first investigated during 1923-1925 by M.M Aequator with trenches and shallow tunnels, but analytical results were disappointing, and only limited work was done. The Aequator mining company reports speculate that the Kulit Manis Vein is the top part of the Rumput Pait Vein. The Top tunnel, mentioned during discussion of both veins, may be the Top Level marked on the Rumput Pait mine map (Fig. 51).

4.5.2 Structural and geological details

The orientation is reported in the 1924 M.M. Aequator report as 030/35°E, though it is noted that the dip may be steeper. The host rock is Brani Conglomerate.

4.5.3 Mineralisation and adits

M.M Aequator (1925) report that 34m of tunnel were built in 1924, but no precious metal of significance was found. In 1925 (M.M. Aequator, 1926) the vein was investigated in three different places with short tunnels, though results were again disappointing. The following analytical results are reported, but probably these relate to some of the best samples.

(top tunnel)	2.5m	10.2g Au	25g Ag
best sample H. wall	40cm	4.8g Au	35g Ag

P.T. Aneka Tambang (Maas 1979) collected samples from a vein they called Kulit Manis, but as they state that the Rumput Pait adits are all inacessible, they may in fact have been directed to the Rumput Pait adits on the south side of the B. Kulit Manis ridge, a possibility supported by the moderate precious metal content reported.

2.5m, 005/40°E 1.22ppm Au 10.68ppm Ag.

4.6 The Boengsoe zone

All of the information about this occurrence is derived from the M.M. Aequator annual reports of 1924 and 1928. The Boensoe Fault (NE/SW), described previously as possibly being the fault cutting out the southern part of the Mangani Vein, was apparently quite well mineralised, and in some reports is discussed as if it was a vein.

In 1924 tunnels had reached the point where the Brani Vein and Mangani (Boengsoe?) Fault should intersect, but no ore was found. The Boensoe "vein", where cut, gave more the impression of a fault with mineral clasts dragged along it, than a primary vein.

In 1928 tunnel III cut the fault, where a three metre irregularly mineralised zone was found.

sample no BSE	1	trace	100g Ag
	2		665
	3		1020
	4		60
	5		60
	6	0.5	49

Tunnel IV found a small quartz vein after 61m

B	61	trace	60

It was not known if this was the same mineral zone as encountered in tunnel III.

These high silver values suggest that such an occurrence would be of interest, but there is no mention of the width of the mineralised zone. If the mineralisation in this zone is primary, rather than consisting of breccia dragged along the fault, then faults with this orientation were available for mineralisation during the deposition of the Mangani mineralisation, and there may be other veins with this orientation.

4.7 The Egert I Vein

The Egert Zone (Vein) is one of the faults which may have cut the southern part of the Mangani Vein. Unfortunately an Egert Vein to the east of the Mangani Vein is marked on many maps, so to distinguish these occurrences, the easterly vein has been called the Egert II Vein.

During the present period of field work a highly silicified pyritised zone was found to the west of the Mangani Vein, as well as an adit, though no actual vein material could be found. The adit ended after about 15m, but this may have been due to a roof fall.

The following results derived from the 1923 M.M. Aequator annual report relate to the vein-mineralised zone west of Mangani. The vein is thicker than the sample width described.

2.5m	9g Au	162g Ag

4.8 The Mangani North Vein (Zwarte - black vein)

Information about this mineralisation is derived from M.M. Aequator mining reports. Different publications show the position of the Mangani North Vein in different places, mine maps showing the tunnels on the south bank of the Galanggang Kiri. The Reinier/Gorge/Gulley mineralised zone discovered during the present period of investigation may be the Mangani North Vein, but occurs further north than the adit marked on the mine map, and does not match the description of being a black vein. To the NW of the Reinier Vein an old sample trench was found cut into the soil, which suggests that this mineralisation had been discovered previously. The geological map by Eklund showing vein locations published in De Haan et al. (1933) shows a North Vein in the northern part of the Rumput Pait stream.

The M.M. Aequator description (1920) is of a vein found in the Galanggang valley by Ir. Geist. It was cut by tunnels close to the surface, but no significant ore was found.

1920	1.6g Au	102g Ag
	0.5	70
	1.0	78
	0.5	50

Samples consisted of black manganese dioxide and quartz. Plans were made to extend the Young Level transport gallery by 250m, to end up 140m below the outcrop, but no mention of this is made in later mine reports.

4.9 The Reinier/Gorge/Gulley Vein mineralised zone

4.9.1 Introduction.

This mineralised zone containing a number of veins was discovered during the present period of investigation. This may be the Mangani North Vein described in M.M. Aequator reports, though none of the different locations shown for this vein on old maps correspond to this zone.

4.9.2 Geology.

Figure 54 shows a detailed geological map of this area, and also sample numbers. This area is located just to the north of the edge of the Mangani Graben, along a N/S fault zone. Most of the rocks in the immediate area are Sihapas Formation quartz conglomerates and quartzites, but much of the mineralisation is hosted in, or adjacent to altered tuffisite dykes. This is one of the places where it can clearly be demonstrated that the tuffisites have a dyke shape, as quartzite outcrops can be found on either side. Thin section examination has shown that these rocks are not igneous dykes, as grains have a granular, rather than crystalline appearance.

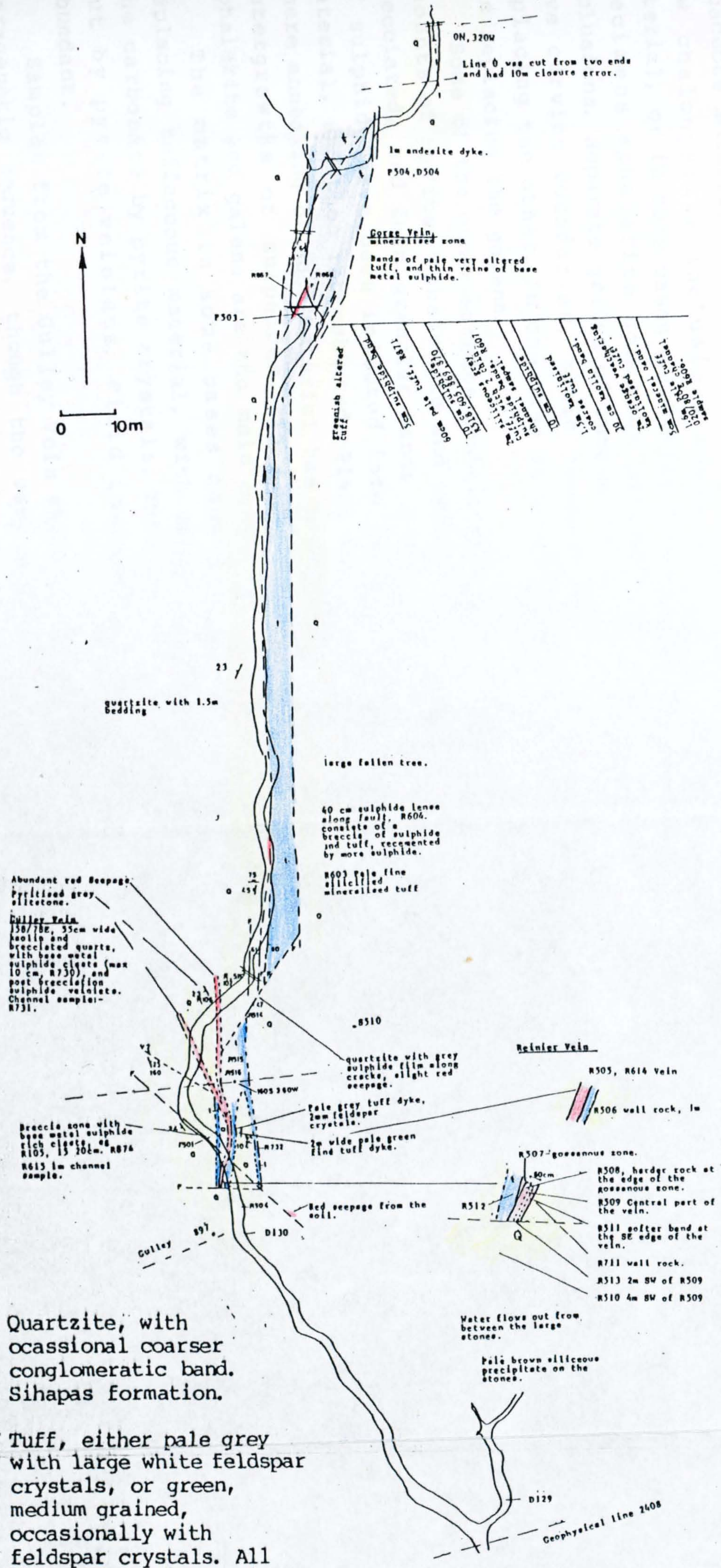
4.9.3 Mineralisation

The Reinier Vein shown on the geological map consists of kaolinised, possibly altered tuffaceous material, and quartz-rich zones, containing disseminated sulphides. In some places a gossanous zone is probably the remains of a more massive sulphide band. This vein appears to continue northward to the west of the gorge, a very large area of red seepage occurring to the west of the first waterfall. Attempts to collect vein specimens from this zone failed, as the zone appears to consist of clasts of quartzite and volcanics cemented by gossan.

The Gorge Vein is not really a vein, but a zone in which thin bands of massive sulphide, and in places thicker bands of kaolinised and silicified material are hosted in a tuff dyke located along a N/S fault.

The Gulley Vein consists of a greasy kaolin band containing large clasts (max 20cm diameter) of massive sulphide, the whole zone being cut by quartz and sulphide veinlets.

Geological map of the Reinier/Gorge/Gulley Vein mineralised zone.



Q Quartzite, with ocassional coarser conglomeratic band. Sihapas formation.

t Tuff, either pale grey with large white feldspar crystals, or green, medium grained, occasionally with feldspar crystals. All tuff is frequently highly silicified, kaolinised and brecciated. Disseminated pyrite is common, as well as veinlets of sulphides. The field relations suggest that much of the tuff-like material in this area is intrusive tuffisite, in dyke-like bodies, though there is no morphological or petrological difference.

Waterfall over 4m high.

Fault (inferred), orientation and amount of dip .

Dip and strike of bedding.

Dip and strike of jointing.

Figure 54. Geological map of the Reinier/Gorge/Gulley Vein area.

Red seepage from the soil in two other places suggests that other mineral localities are present.

The whole zone appears to be cut by a NW/SE fault, which contains large clasts of masssive sulphide material, as well as tuffaceous material impregnated by sulphides.

4.9.4 Petrology

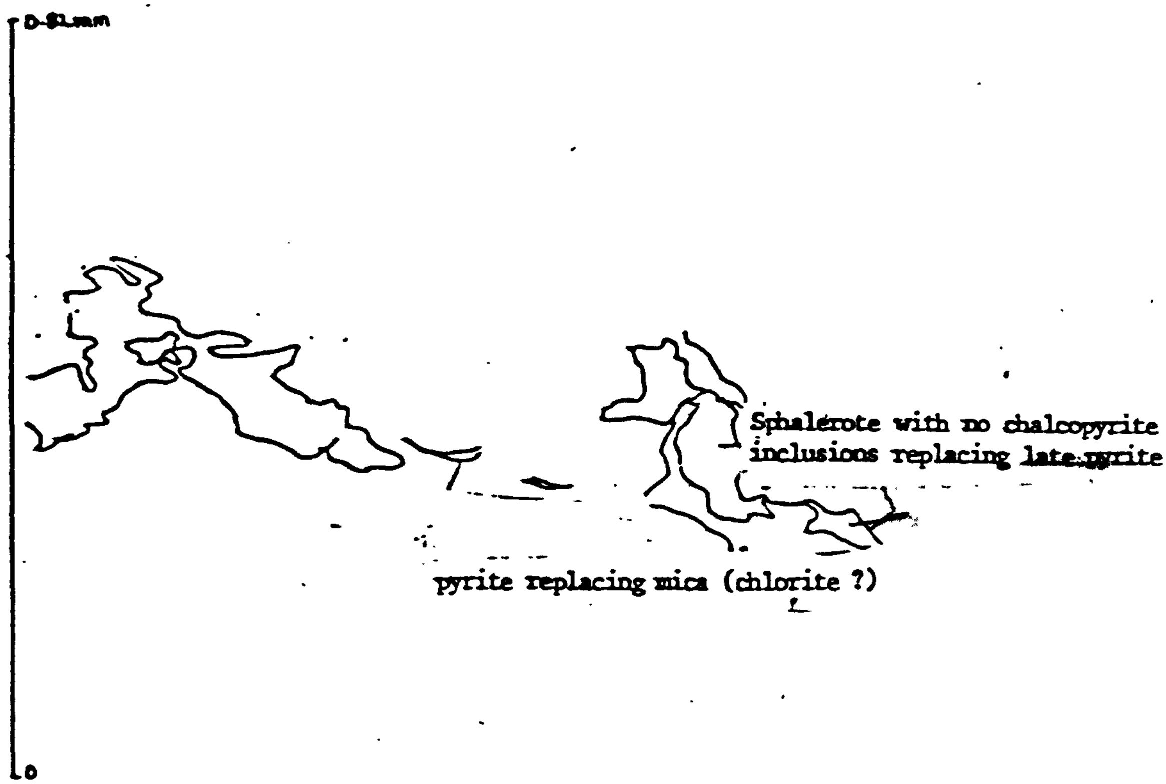
Polished sections made from 12 different samples were used to compile the following description of the petrology of these veins. Most samples of sulphidic material suitable for examination in polished section were collected from a number of thin sulphide bands in the Gorge Vein (Fig. 54), though the Gulley Vein also contained clasts of massive sulphide.

In the Gorge Vein samples early brecciated colloform pyrite with dusty brown inclusions are overgrown by pyrite grains (Plate 16a), which themselves often show signs of brecciation. In some cases pyrite appears to be replacing micaceous material (Plate 15a). Later sphalerite with very few chalcopyrite inclusions replaces this earlier material, or in some cases sphalerite rims pyrite. In some specimens sphalerite contains pyrrhotite or galena inclusions. Separate grains of sphalerite and galena often have curving boundaries, again suggesting that one is replacing the other. In one case it appeared that quartz was replacing the galena.

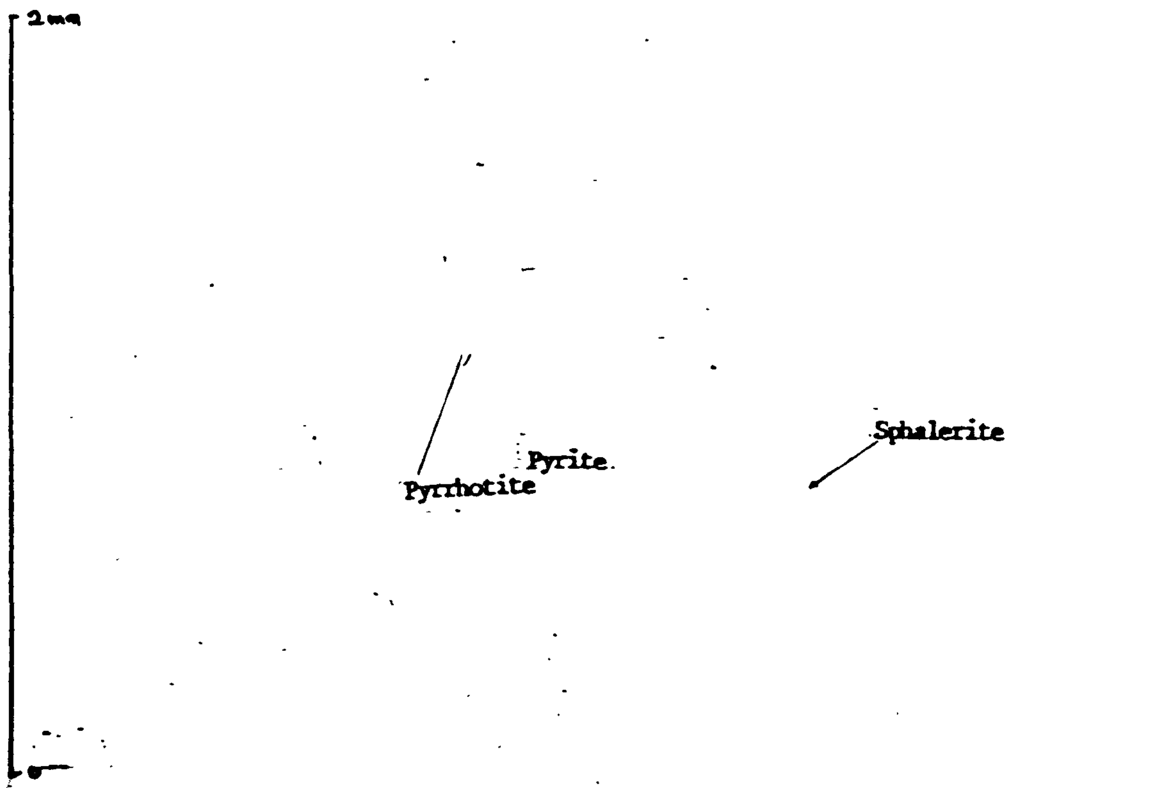
Some of the other samples contain approximately equal amounts of pyrite, sphalerite and pyrrhotite are finely brecciated, and form granular bands (Plate 15b). Veinlets of sulphide have been injected into already brecciated material, and then rebrecciated. Plate 16b shows a sample where annealing of such material has resulted in irregular intergrowths of sulphides. In this specimen pyrite, sphalerite and galena are the main constituents.

The matrix in some cases consists of dolomite replacing tuffaceous material, with later replacement of the carbonate by pyrite crystals. This material is then cut by pyrite veinlets. Fluid inclusions are quite abundant.

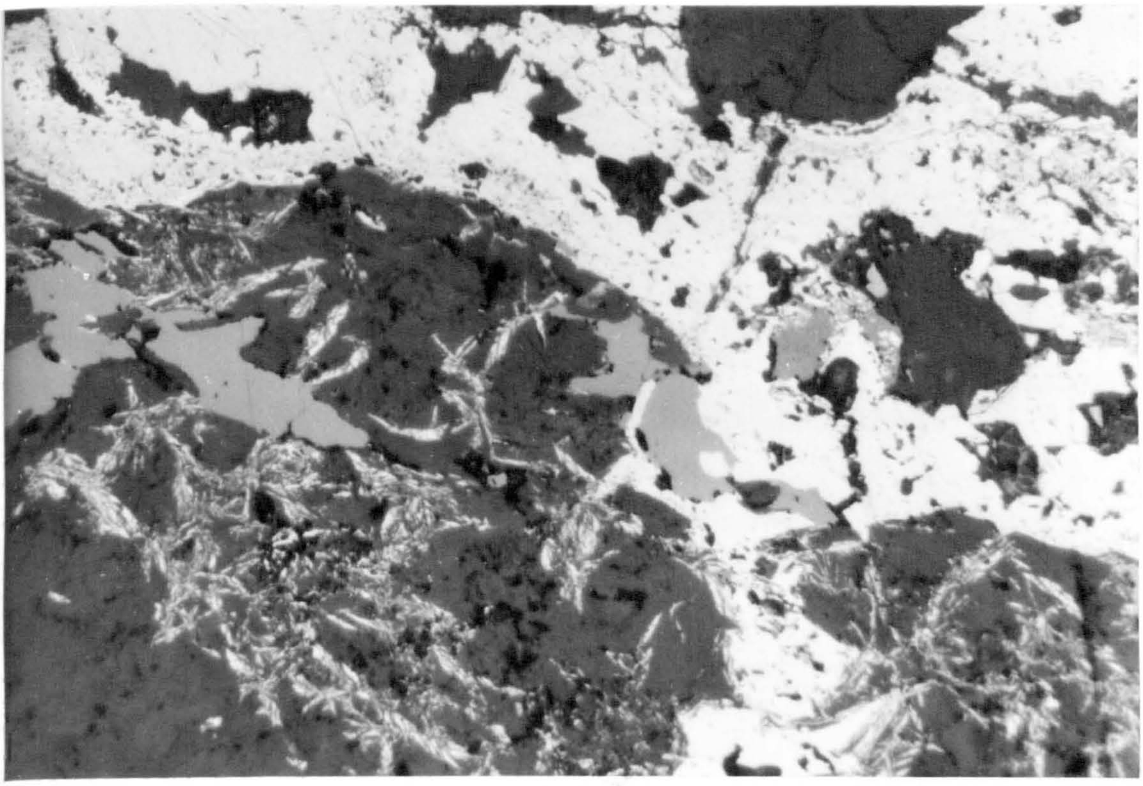
Samples from the Gulley Vein showed a very similar paragenetic sequence, though the very highly brecciated, granular texture shown in Plate 15a was not encountered.

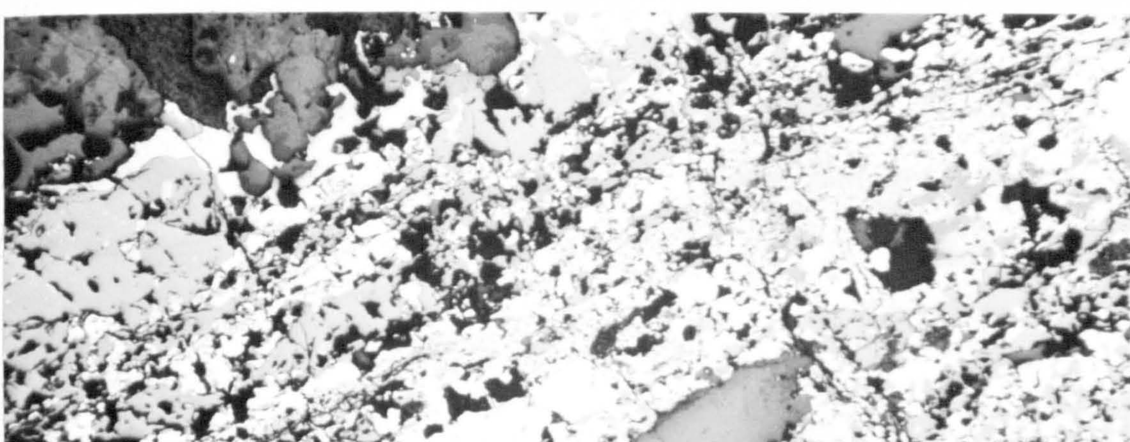


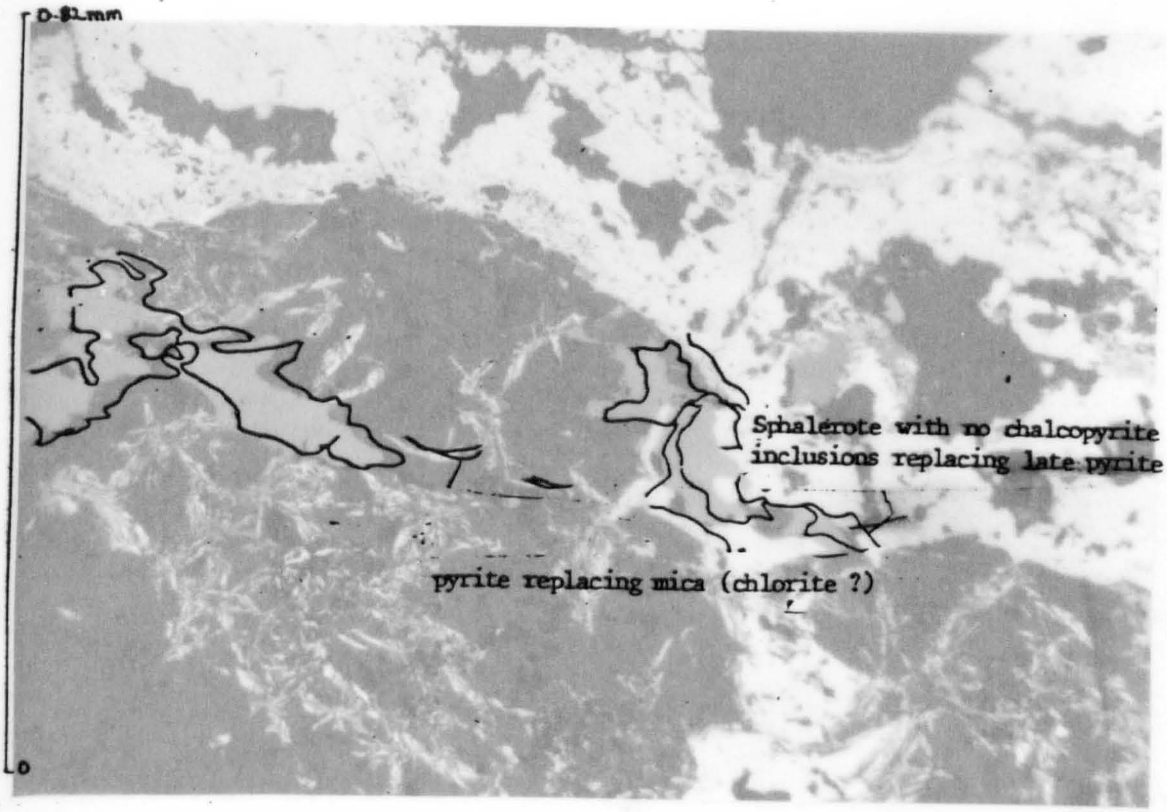
a. Photomicrograph of a polished section from the Gorge Vein (GO5), showing the replacement of micas by sulphides.



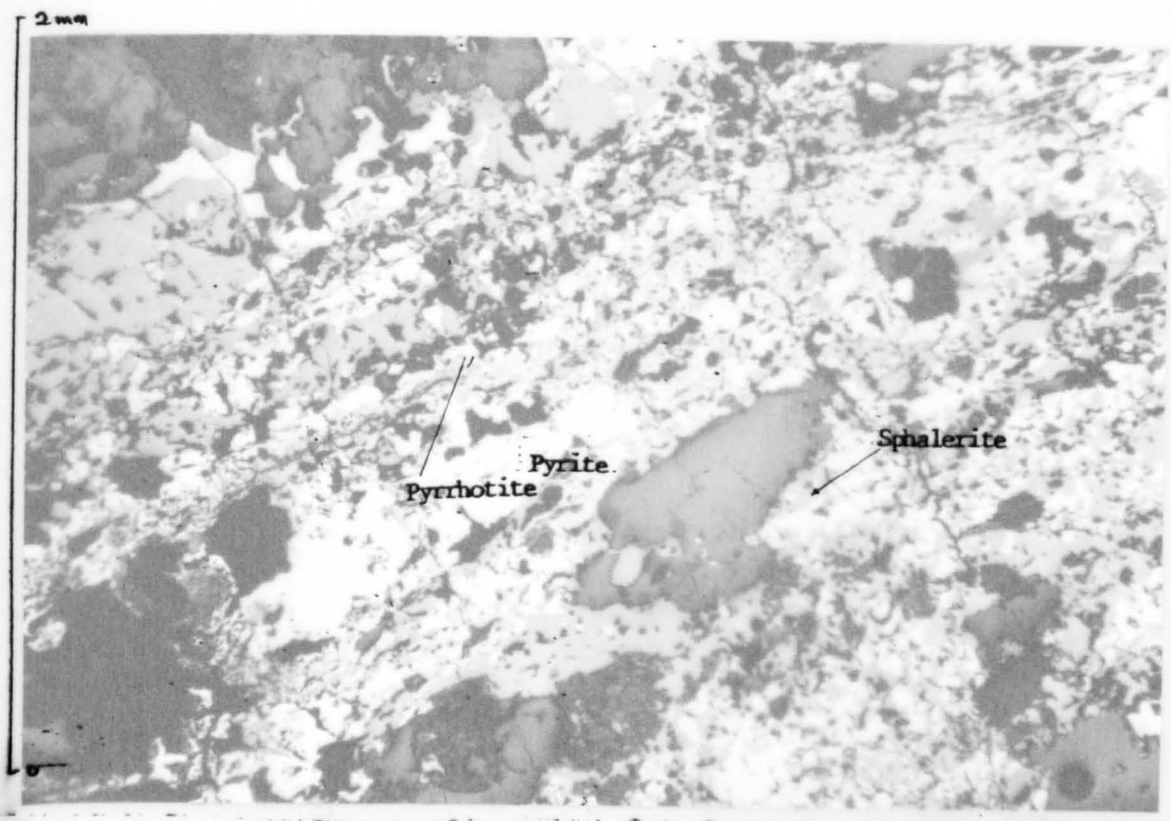
b. Photomicrograph of a polished section from the Gorge Vein (GO5), showing finely brecciated sphalerite, pyrrhotite and pyrite.





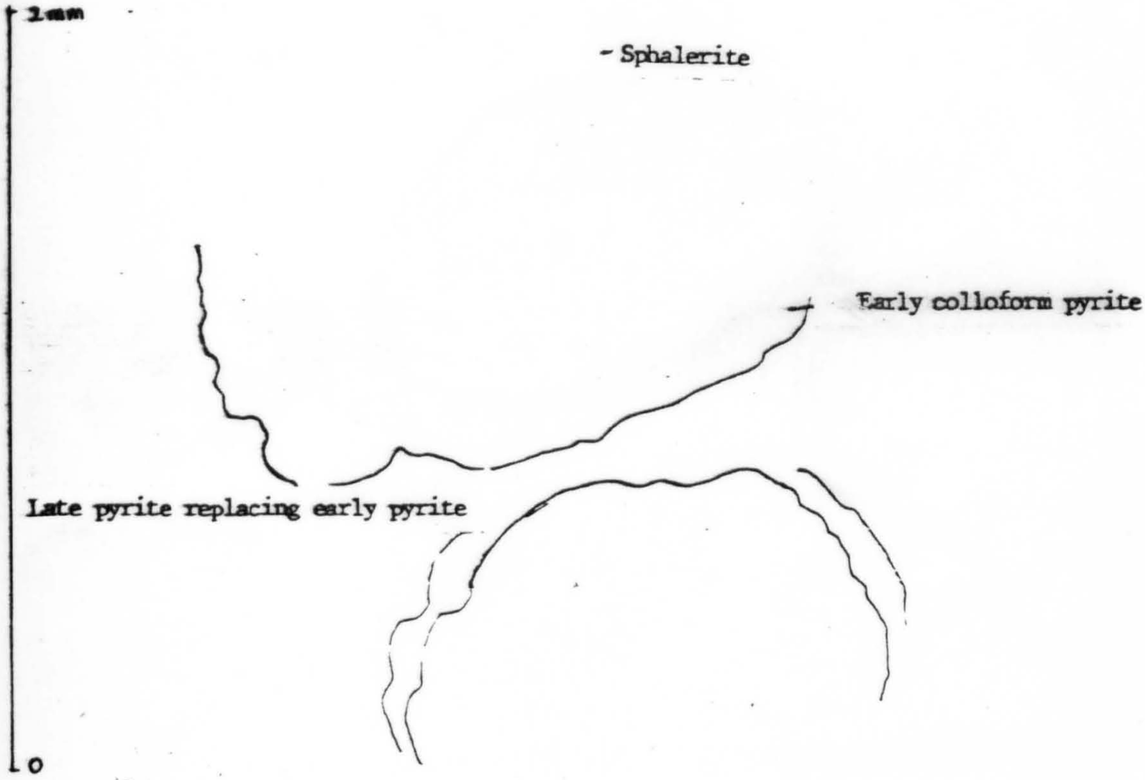


a. Photomicrograph of a polished section from the Gorge Vein (GO5), showing the replacement of micas by sulphides.

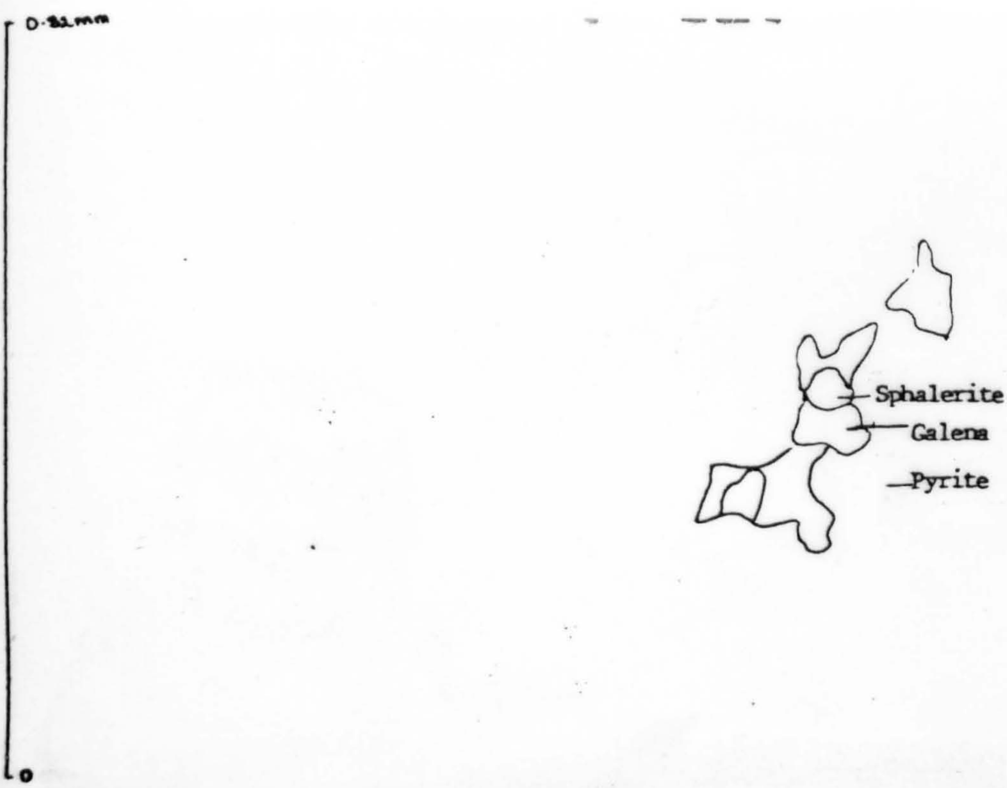


b. Photomicrograph of a polished section from the Gorge Vein (GO5), showing finely brecciated sphalerite, pyrrhotite and pyrite.

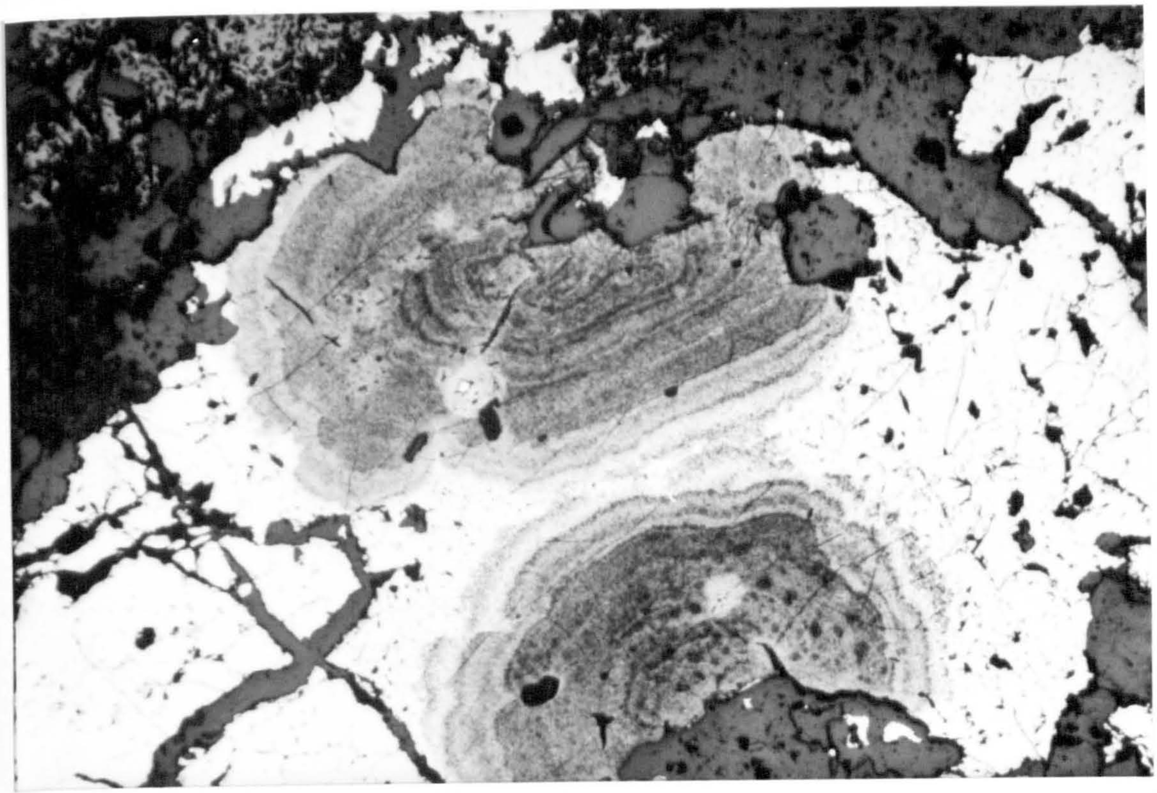
Plate 16



a. Photomicrograph of a polished section from the Gorge Vein (GO1, Ma R604), showing early colloform pyrite in later pyrite veinlets.



b. Photomicrograph of a polished section from the Gorge Vein (GO5, Ma R518), showing annealing textures.



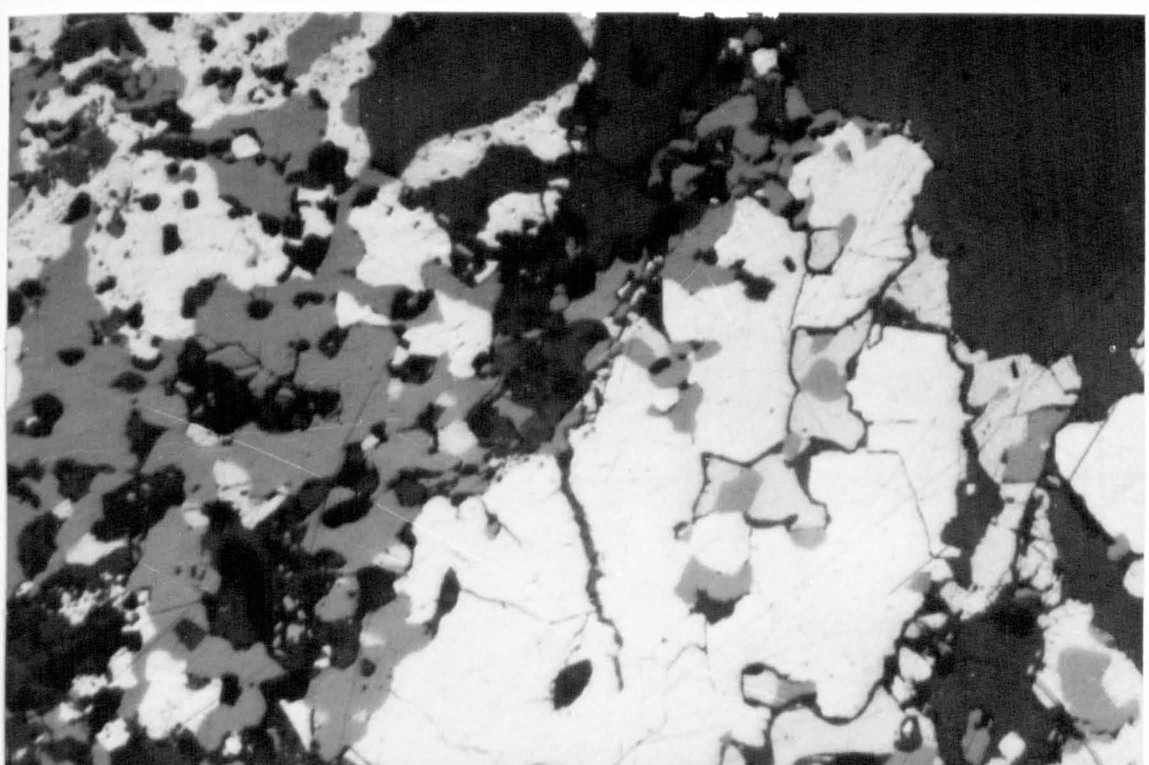
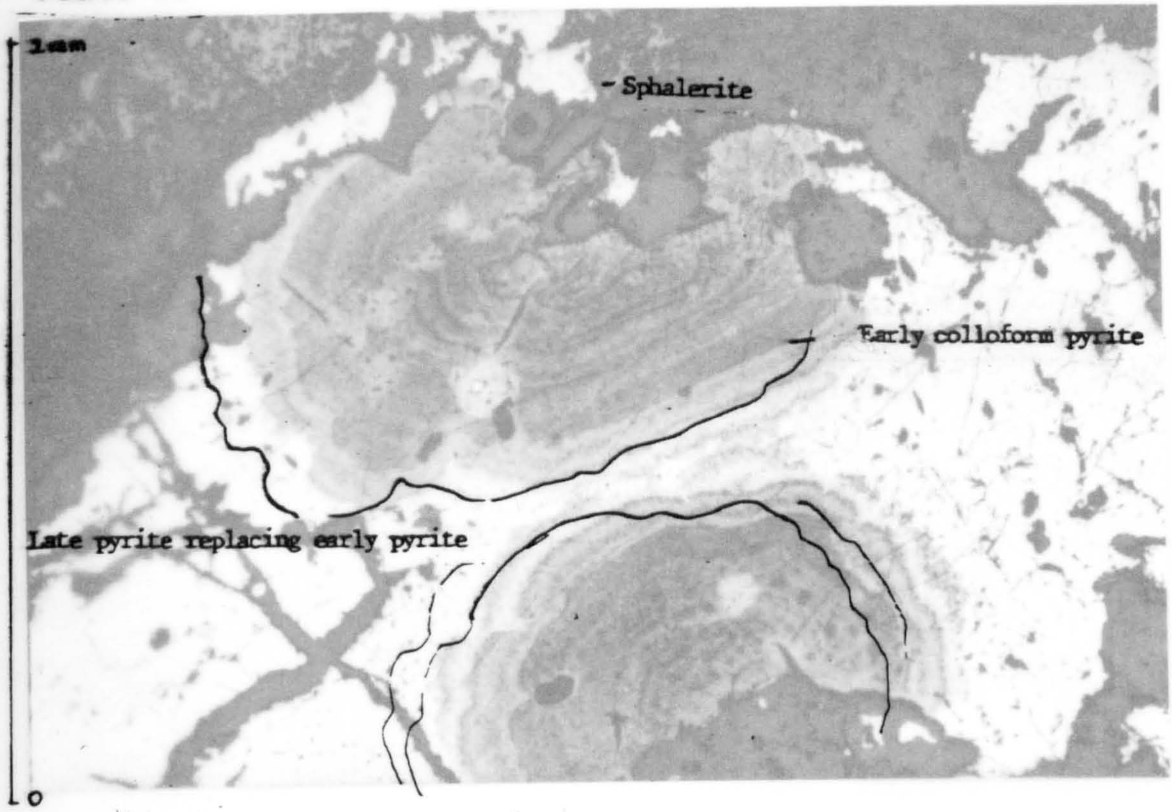
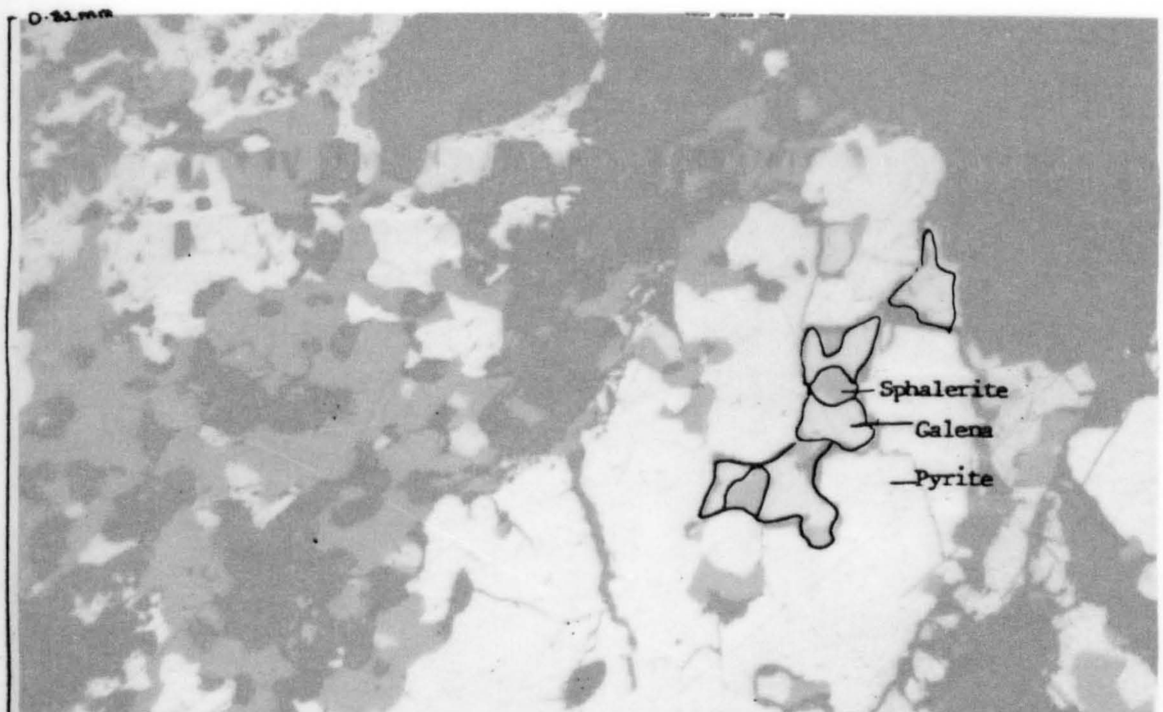


Plate 16



a. Photomicrograph of a polished section from the Gorge Vein (G01, Ma R604), showing early colloform pyrite in later pyrite veinlets.



b. Photomicrograph of a polished section from the Gorge Vein (G05, Ma R518), showing annealing textures.

Samples from the Reinier Vein were generally too oxidised, with only pyrite and iron oxides still recognisable. In one specimen scattered pyrite, chalcopyrite and sphalerite grains occurred in an altered tuffaceous matrix, suggesting that these minerals initially occurred as disseminated grains in some of the other areas, and may have been remobilised to form some of the massive sulphide bands seen in the Gorge Vein.

The information above suggests that this mineralisation, like that in the Mangani Vein, formed as a result of a long process of mineral deposition, deformation, and replacement. The presence of large amounts of early pyrrhotite in some samples suggests an initially lower sulphur content.

Generally very few similarities between this material, and the Mangani Vein ores can be seen.

4.9.5 Analytical results

The location of the samples (for which the analytical results are shown in Table 7) are shown in Figure 54.

Table VII Analytical results from the Reinier/Gorge/Gulley Veins.

Sample	Cu	Pb	Zn	Mn	Ag	As	Ni	Co	Cd	Fe%	Bi	Cr
606	190	470	1250	7390	5	8.0	10	14	6	6.6	<0.5	4
607	345	1.80%	1.78%	1.37%	7	75	23	26	51	5.7	<0.5	2
614	185	1.54%	86	170	60	4500	4	17	2	12.8	5.5	2
615	365	1990	1.17%	3970	5	50	5	27	48	8.9	2.0	2
731	520	6290	2.5%	2550	24	220	10	55	103	10.4	40	2
731	520	6260	2.0%	2550	24	250	11	56	103	10.6	40	2

Sample	Cu	Pb	Zn	Mn	Ag	As	Au	Sb	Sn
867	26	48	270	1.75%	<1	12	<0.05	4	14
870	1150	3400	5.9%	6200	24	700	<0.05	30	790
874	1100	2500	7.4%	1.05%	22	180	<0.05	20	65

These results are in ppm, except where otherwise indicated

The following sample was collected by CSR Ltd, reportedly from the Mangani North Vein, but probably came from the Reinier Vein.

	Au	Ag	Cu	Pb	Zn	As	Bi	Mn	Mo ppm
A99654	0.04	0.7	6	<2	44	12	<0.5	2540	2
	0.06	0.62							

Some of these samples are massive sulphide clasts from within a fault zone, and the lead and zinc content is high. Generally the copper content is only moderate, but the manganese content is always high. The high manganese content of some of the massive sulphide samples suggests that alabandite is present, as in the Mangani Vein, and the presence of Sb and Sn suggests that these may be related to the Mangani A-ores. Unlike the Rambutan Tinggi Vein, which also lies to the north of the Mangani Graben, the silver content is only moderate, and the Bi content is low, except in R731. A number of base metal rich samples have a very high arsenic content, suggesting the presence of arsenopyrite. Ni, Co, and Cr are not abundant, again suggesting that manganese is unlikely to be directly derived from basic rocks. Cadmium and zinc often show a correlation as they are chemically very similar, but in this case the cadmium content is only moderate, and is not directly correlated to the zinc content. The iron content in all samples is high, reflecting the high pyrite content. Gold is present in very small amounts in the sample collected by CSR Ltd, suggesting that if this sample comes from this area, that this mineralisation may not be as barren of gold as the samples collected during the present investigation indicate.

4.10 The Egert II Vein

4.10.1 Introduction

This vein is shown on the map published in De Haan et al. (1933) occurring to the east of the Mangani are, though a vein/mineralised fault zone with the same name is shown on M.M. Aequator maps west of the Mangani Vein. During the present investigation a quartz-calcite-manganese and limonite rich zone was investigated to the east of the Mangani Vein.

4.10.2 Geology

Outcrop near this vein is limited, but much of the zone consists of extremely altered and veined tuff. Figure 55 shows a geological sketch map of the vein outcrop, and the location of samples.

4.10.3 Mineralisation

Figure 56 shows the analytical results for this vein.

Most of the other veins for which samples were analysed showed little correlation between the elements, or the elements were divisible into groups which behaved in a similar way. The Egert II Vein samples show a good correspondence between the distribution of the different elements. This may possibly be caused by Mn scavenging of the other elements.

This vein can be categorised as having a moderately high base metal content, high iron (pyrite?) and manganese content, and a moderately high antimony content. The As content is high, but the silver content only moderate. Sn is present as a few ppm, and one sample contained some gold.

The high calcite content suggests that this may be connnected with the early gold-poor mineralisation period related to the Mangani East Vein, which also had a high manganese and base metal content. If this is the case, then further investigation of this occurrence may be necessary, as the later East Vein mineralisation period was characterised by high precious metal contents.

5 specimens were collected for thin section examination, but in all cases were too oxidised for any recognisable sulphide minerals or textures to be found. Most samples consisted of very fine grained granular carbonate with some clay minerals, and later scattered irregular quartz grains with very small, but abundant fluid inclusions overgrowing the matrix. Scattered pyrite crystals can be seen overgrowing the fine grained carbonate, and in some cases the quartz grains. Veinlets of haematitic material are partly cross cutting, and partly seem to overgrow dolomite grains, which themselves overgrow the material previously described.

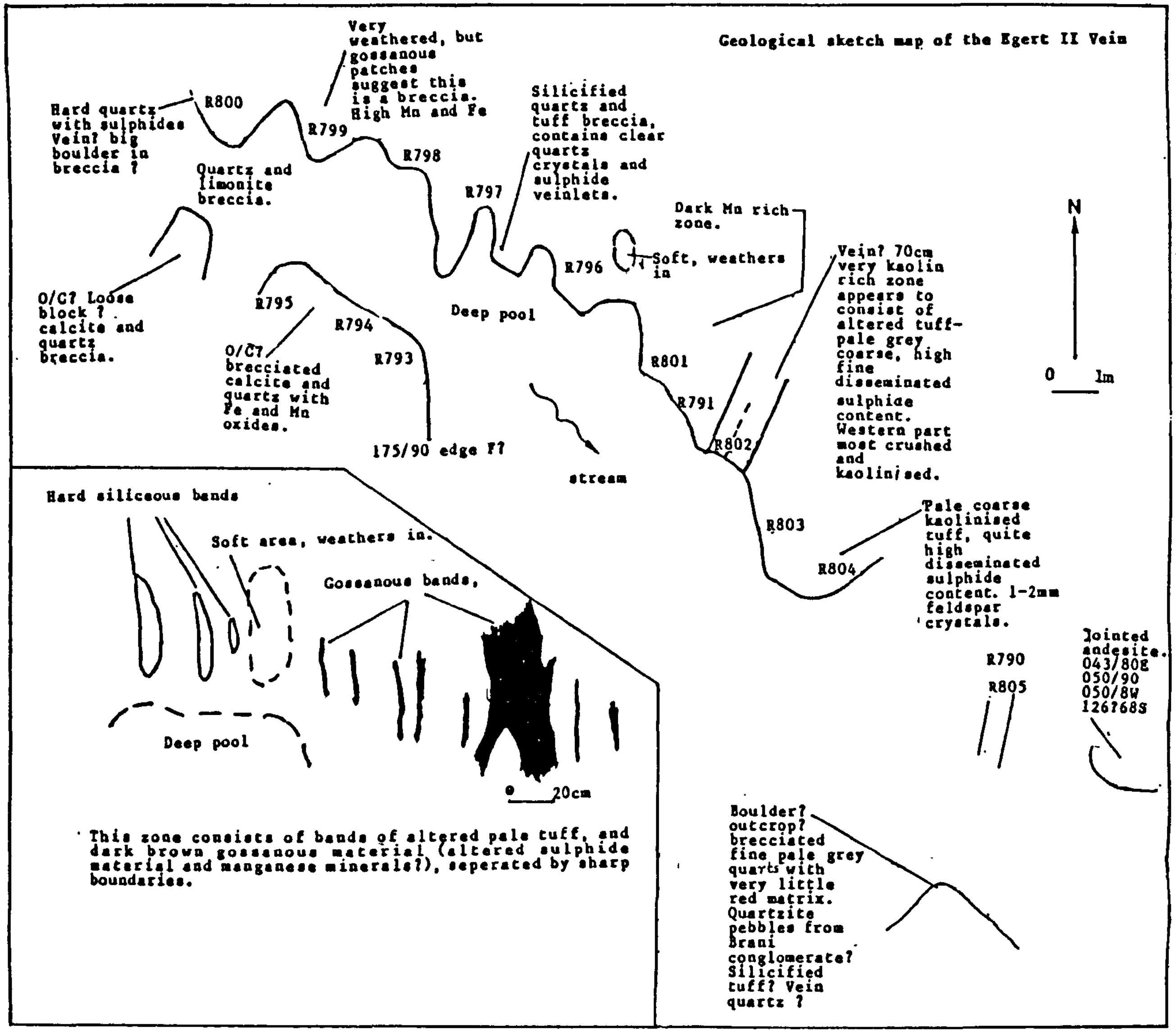
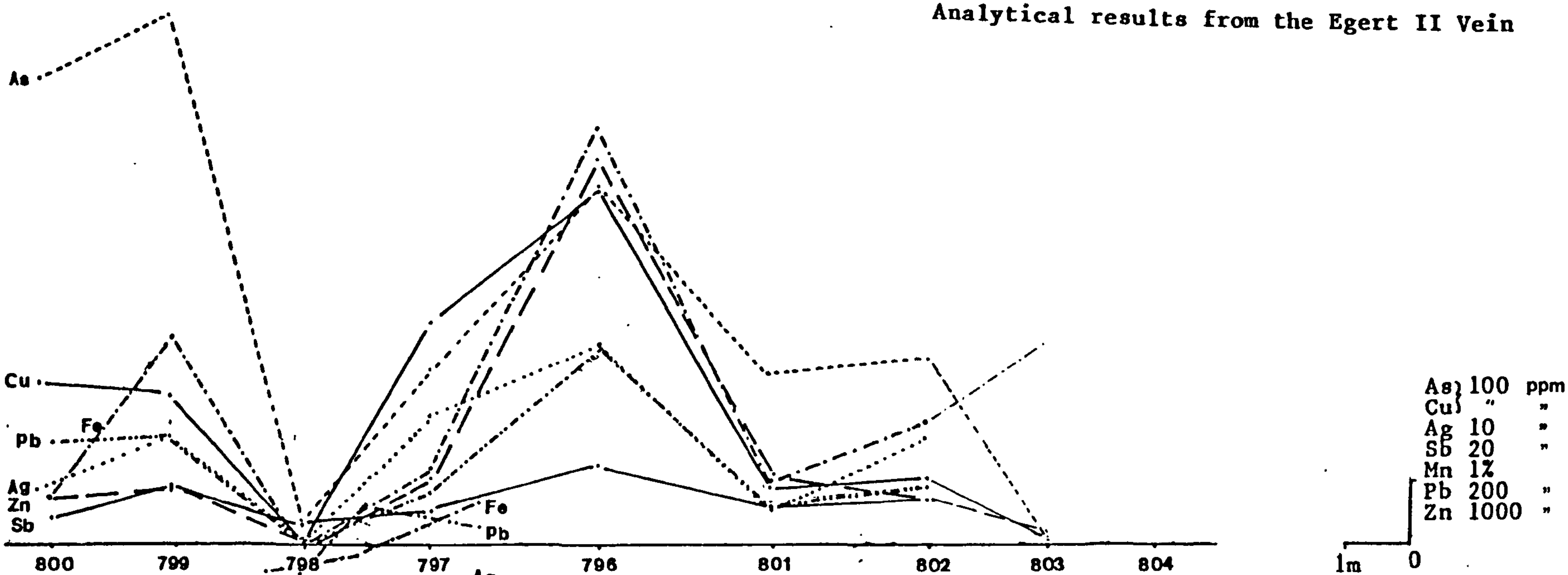
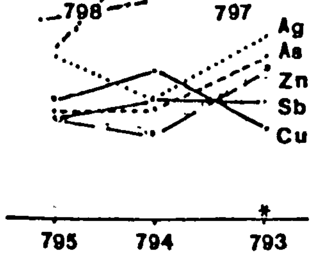


Figure 55. Geological sketch of the Egert II Vein.

Analytical results from the Egert II Vein





Sample	Cu	Pb	Zn	Mn	Ag	Au	Sb	Sn	As	Ni	Co	Cd	Fe%	Bi	Cr
Ma R793	115	720	1950	3.3%	24	0.10	30	-4	105						
R794	190	580	1110	3.6%	15	-0.05	32	8	70						
795	160	510	1300	2.3%	21	-0.05	26	-4	70						
796	530	1250	5800	3.0%	30	-0.05	24	-4	270						
797	330	230	1000	7800	19	-0.05	10	4	130						
798	10	14	105	780	1	-0.05	6	4	34						
799	220	620	820	1.55%	16	-0.05	18	4	400						
800	240	150	750	1.4%	11	-0.05	8	-4	350						
801	90	195	1050	6500	5	-0.05	12	-4	130						
802	100	370	760	9000	16	-0.05	14	-4	140						
803	12	17	20	3.0%	-1					17	17	4	0.2	-0.5	2

Figure 56. Analytical results from the Egert II Vein.

4.11 Linda Vein

4.11.1 Introduction

This vein was found during the present investigation, and is not mentioned in any of the literature about the Mangani area. It is located to the east of Bukit Bulat, in the A. Galanggang Kanan. This was one of the veins whose extent was investigated using detailed geophysics and soil geochemistry (Chapter 5).

4.11.2 Geology

Outcrop to the west of the vein consists of volcanics. To the east the rock consists either of carbonaceous, sometimes calcareous fine to silty mudstones, extensively silicified to look like cherts, or of volcanics. The vein is partly located along the boundary of these two lithologies, along a N/S fault (Fig. 57). Two main areas of outcrop occur about 20m apart, but small outcrops can be found over a length of about 60m, and the geophysical and geochemical response indicates that this vein extends for 80m to the north. Both larger sections of the vein are located in waterfalls, the southern one consisting of three steep to vertical surfaces which may be younger fault surfaces, with a total height of about 15m, separated by two semi-horizontal steps. A tributary of the A. Galanggang flows down over the vein to join with the main stream at the bottom. This outcrop is shown in Plate 17. The northern waterfall occurs in the main stream, and is only about 3m high. The vein may be cut by a fault to the south, though the amount of movement is not large, and this vein is thought to connect up eventually with the Eloise Vein outcrop.

4.11.3 Mineralisation.

The vein consists of a highly altered silicified tuff and mudstone breccia, with veinlets of quartz and sulphide, and a few larger sulphide bands (Fig. 58). A bleached kaolinised band occurs at the hangingwall, below which is a gossanous layer. The kaolin and gossan layer dip at a shallower angle than the steep faces of the

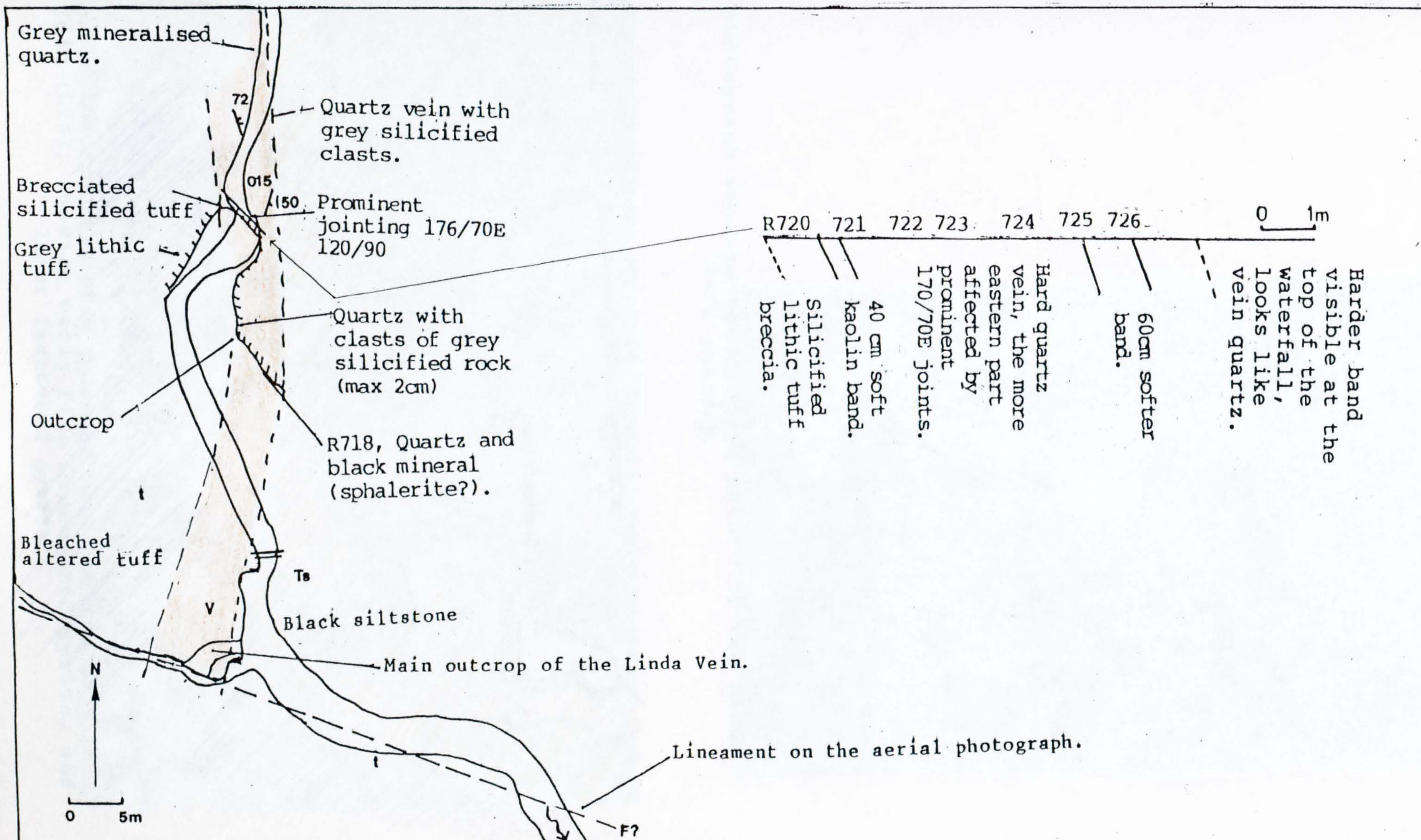
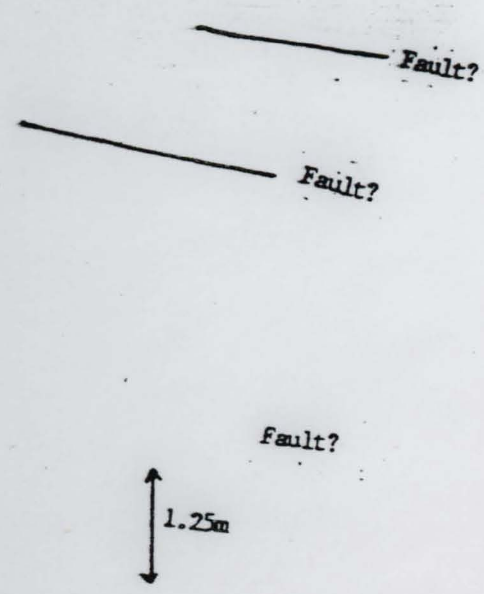
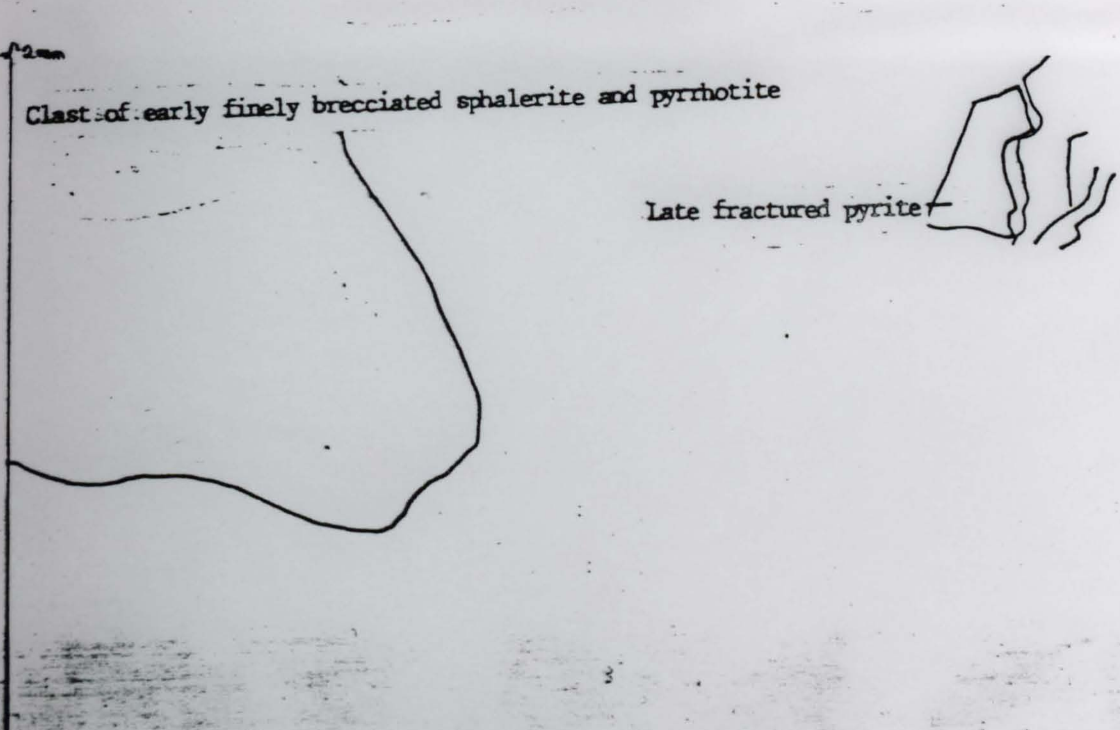


Figure 57. Geological map of the Linda Vein area.

Plate 17



a. Photograph showing the stepped nature of the Linda Vein outcrop.



b. Photomocrograph of a polished section from the Linda Vein (L16), showing early fine brecciated pyrite, and later fractured pyrite.

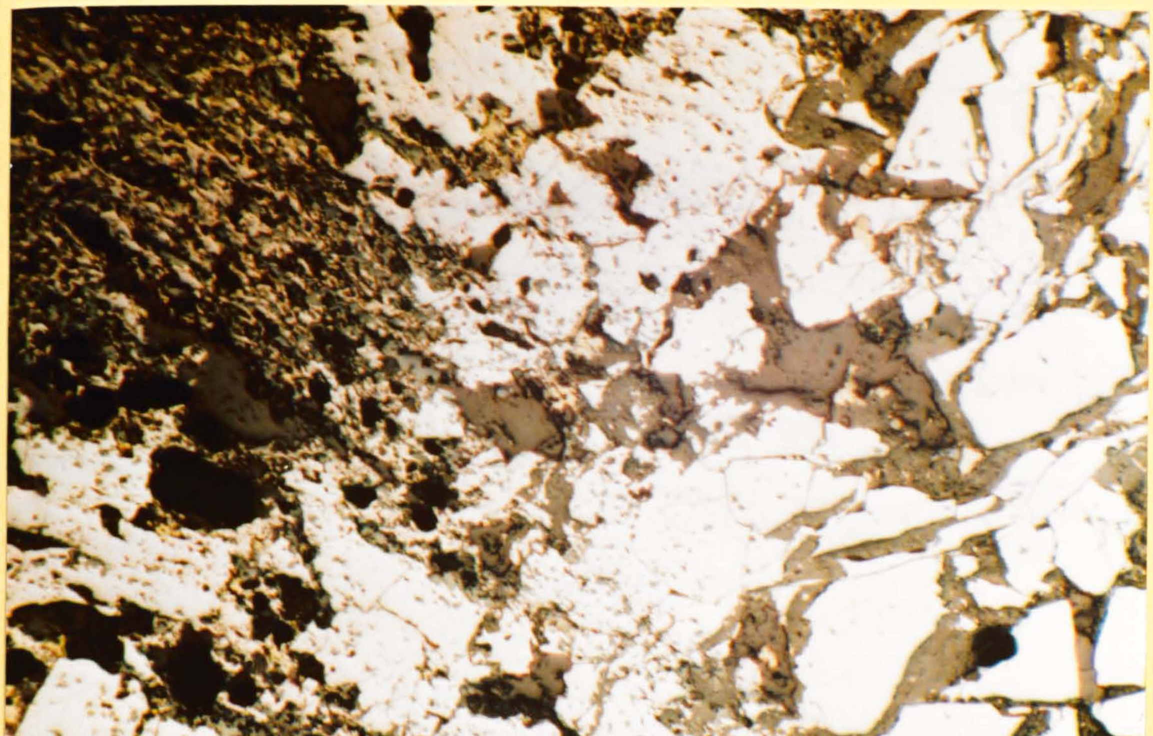
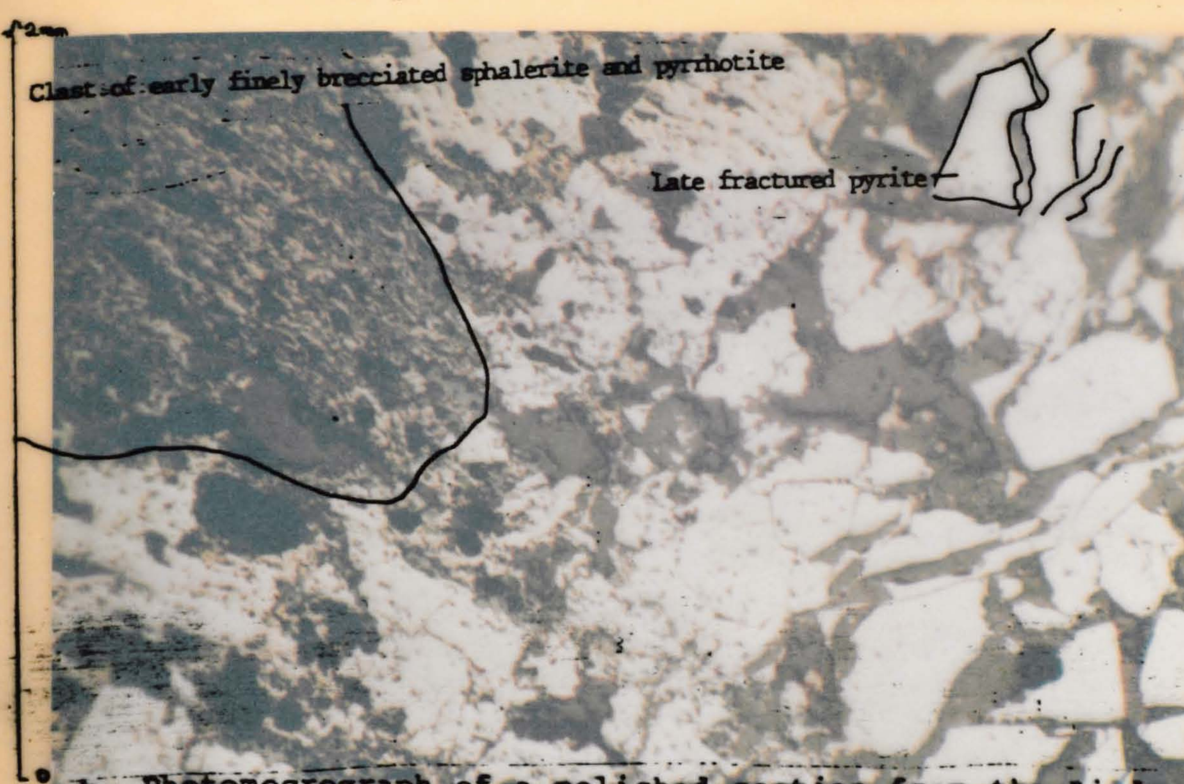


Plate 17

a. Photograph showing the stepped nature of the Linda Vein outcrop.



b. Photomocrograph of a polished section from the Linda Vein (L16), showing early fine brecciated pyrite, and later fractured pyrite.

waterfall, suggesting that the vein has been segmented by later N/S faults with a steeper dip. The total vein width of over 10m at the southern outcrop may have been increased as a result of the later longitudinal faulting.

4.11.4 Analytical results

7 samples were collected from the largest (most southern) area of outcrop (Figs. 58 and 59), 4 grab samples at 5m intervals from the tuffs to the west of this point (Fig. 61), and 8 channel samples from the more northerly part of this vein (Fig. 60). It was not possible to collect a channel sample from the wall rock to the east (Telisa Formation), as the outcrop was limited, though it is probable that these carbonaceous mudstones will contain quite high values of most elements.

The southern outcrop of the vein showed an unusually good correlation between the different elements, with the values of most elements being lower in the central portion of the part sampled, though arsenic showed a negative correlation. Generally the base metal content is high, with several percent zinc occurring in the channel samples, though the lead content is quite low (< 70 ppm). Manganese occurs in appreciable amounts, but silver only occurs in small amounts, and gold appears to be absent. Both the arsenic and tin contents are conspicously high, but antimony is quite low, though present. Bismuth is present, but only in small amounts. The reason for the dark appearance of highly pyritised bands (included in R713) is not clear; in the field it was thought that this colour was due to the high manganese content, but this is not borne out by the analytical results. An alternative explanation is that the colour is derived from abundant finely brecciated fragments of carbonaceous mudstone, and sphalerite. Pods of base metal sulphide consist mainly of sphalerite and pyrite, with 22% zinc, but very little silver and no gold.

The wall rock to the west consists of highly bleached, kaolinised pyritised tuff. Weathering in some cases has resulted in a white and red mottled rock. The visible amount of alteration and mineralisation appears to decrease away from the vein, but chemical analyses (Fig. 61) indicate that the alteration pattern is not that

Figure 58. Detailed map of the southern outcrop of the Linda Vein.

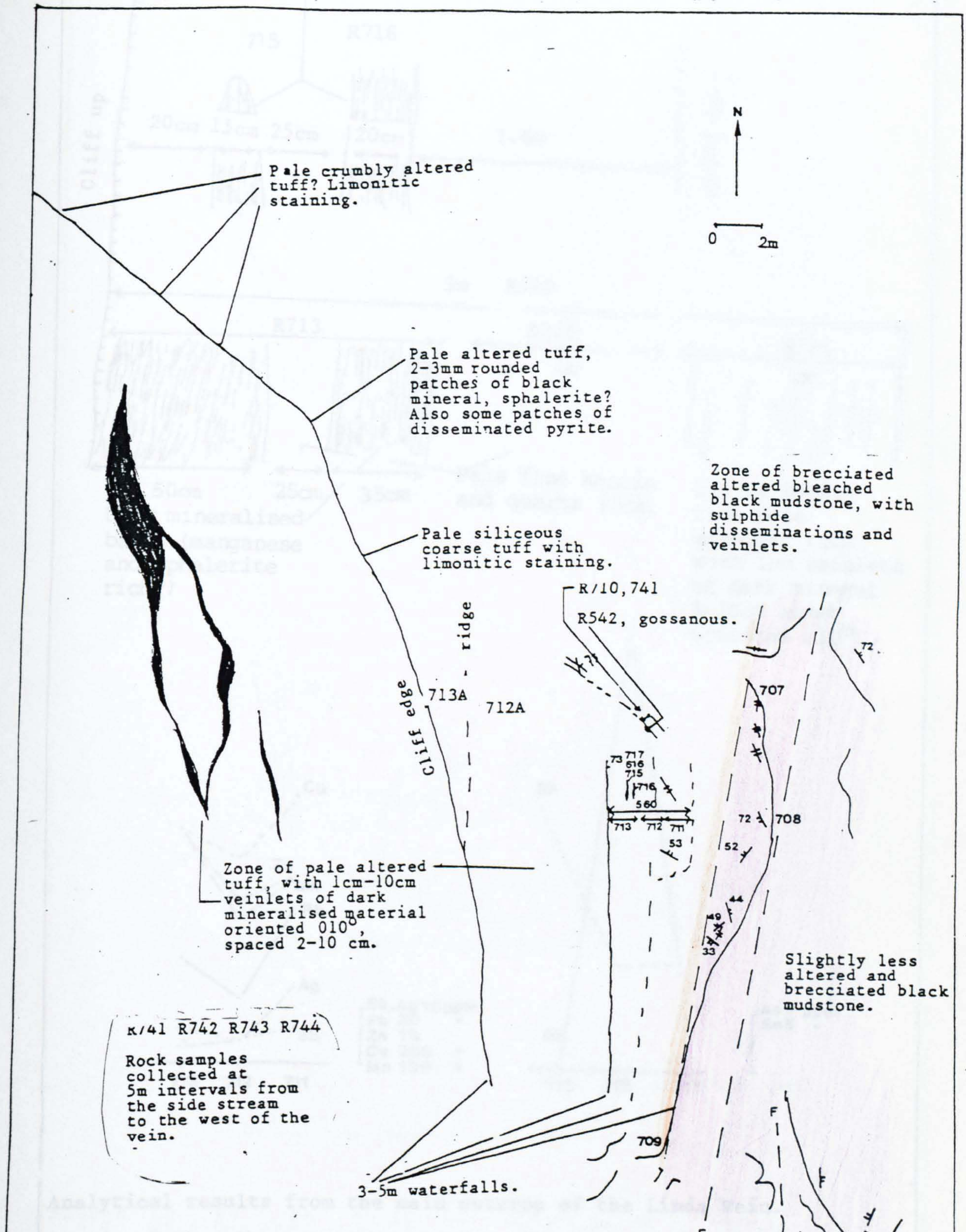
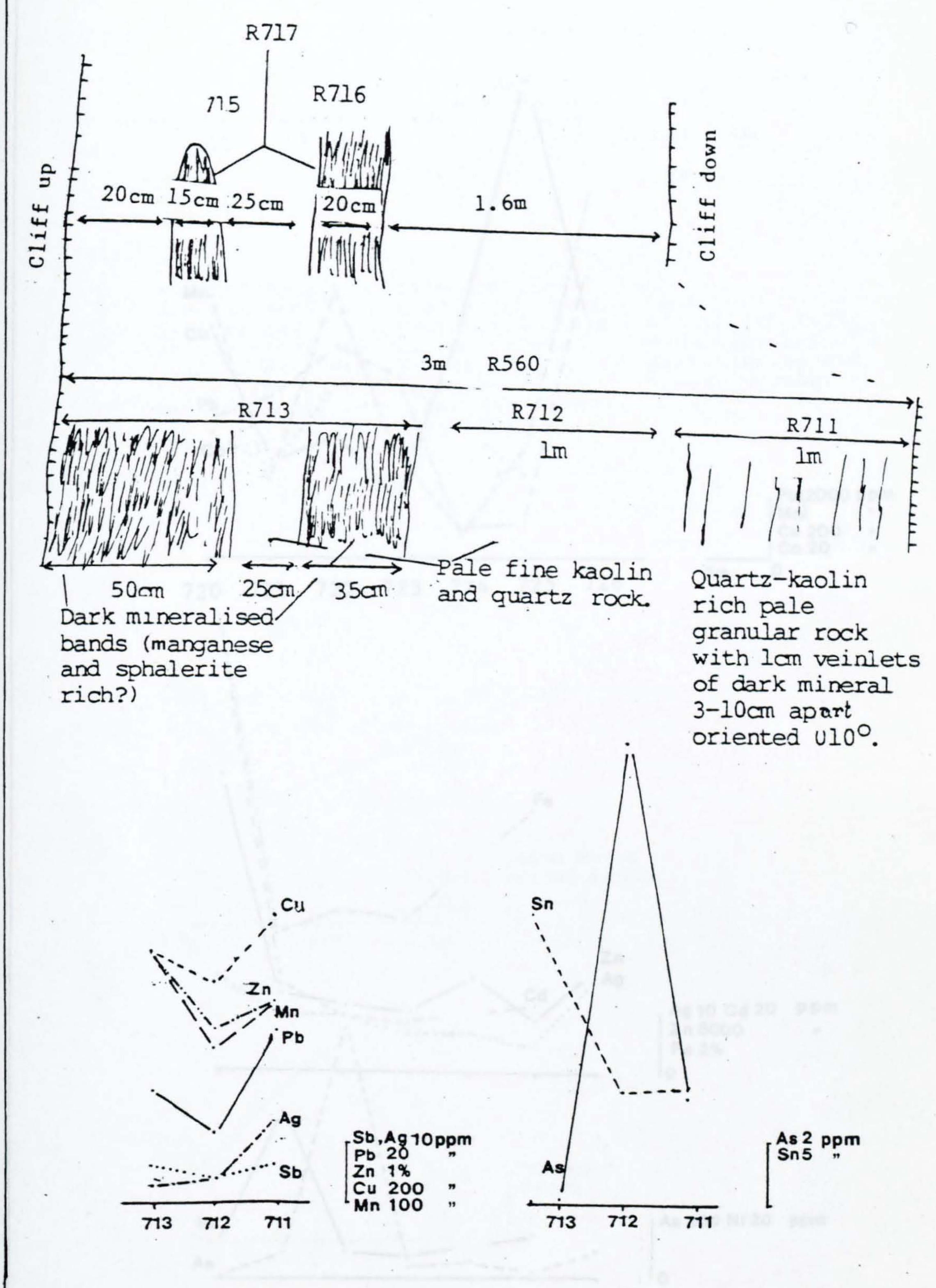


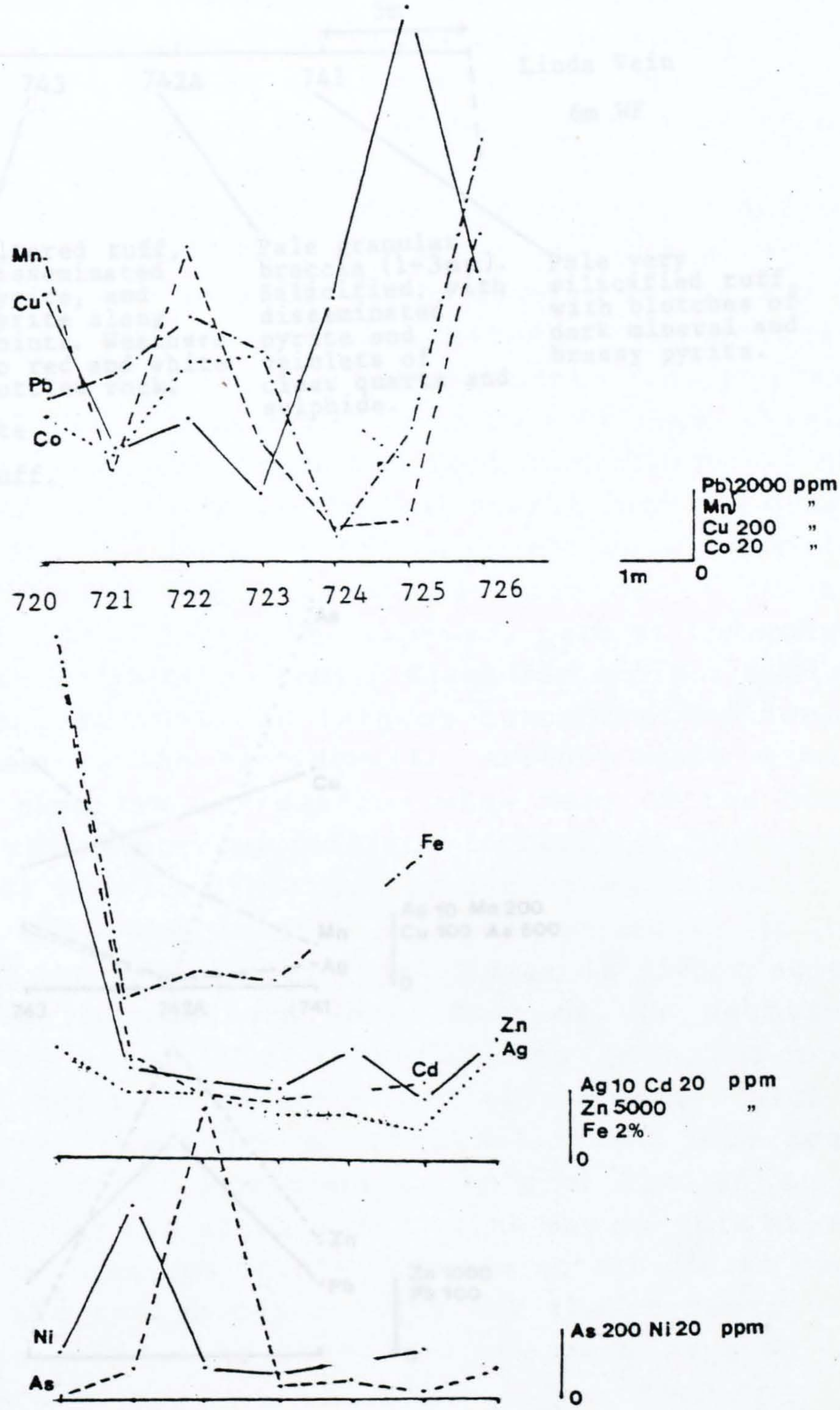
Figure 59. Analytical results for the southern outcrop of the Linda Vein.



Analytical results from the main outcrop of the Linda Vein.

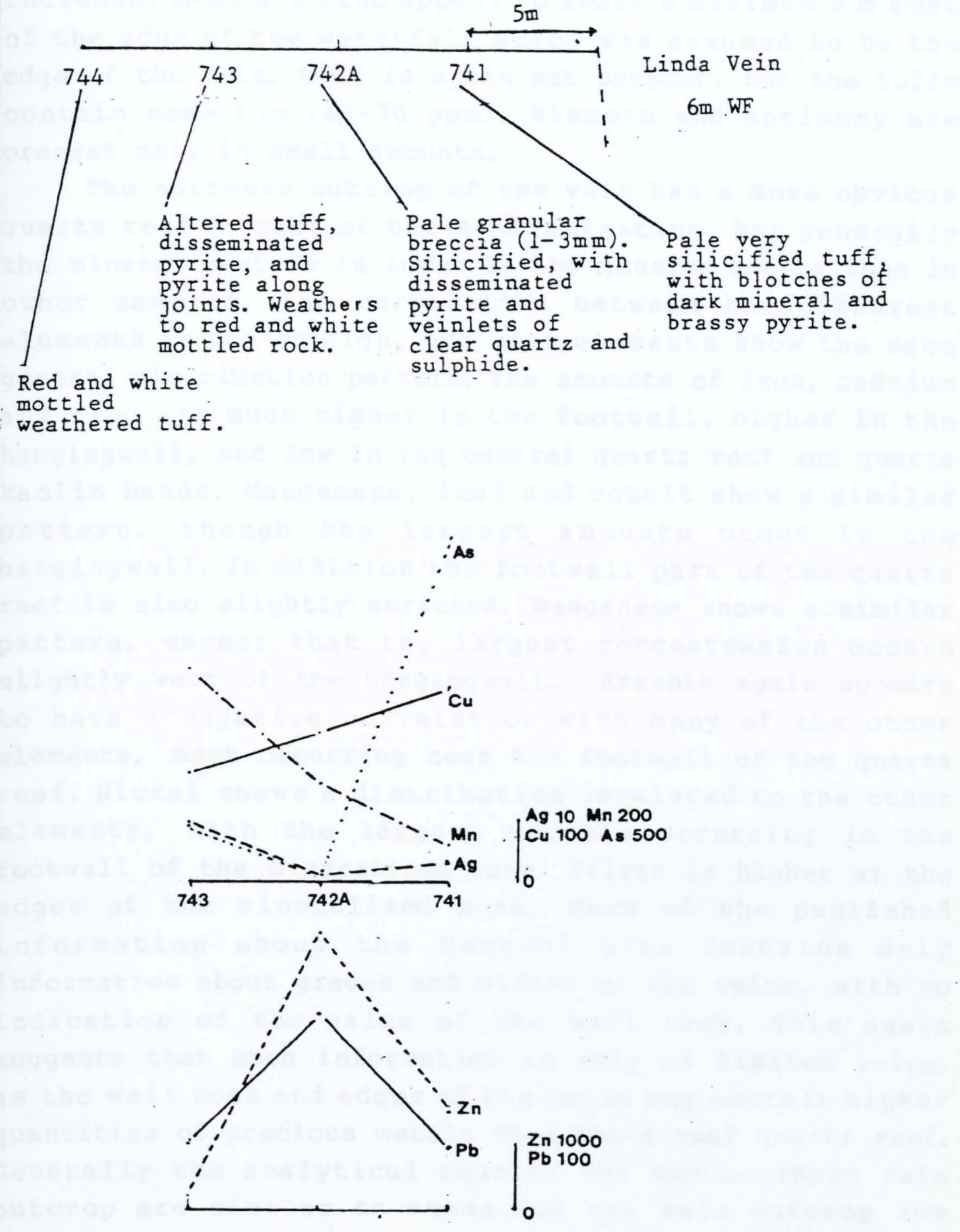
Sample	Cu	Pb	Zn	Mn	Ag	Au	Sb	Sn	As	Ni	Cd	Fe	Bi	Cr	Co
MaR560	1550	1830	1.1%	4170	20				90	5	64	8.1	15	3	22
616	35	27	325	500	42				50	18	3	3.93	0.5	5	13
710	190	70	600	170	7	-0.05	4	115	3100						
711	940	55	3.3%	330	13	-0.05	6	95	3450						
712	700	22	2.8%	250	4	-0.05	4	90	1.48%						
713	800	36	3.9%	400	3	-0.05	6	230	55						
717	1050	70	22.0%	2450	14	-0.05	18	250	6500						

Figure 60. Analytical results for the northern outcrop of the Linda Vein.



Sample	Cu	Pb	Zn	Mn	Ag	Au	Sb	Sn	As	Ni	Co	Cd	Fe	Bi	Cr
718	42	2700	1200	6000	2	-0.05	6	40							
720	840	4330	2.4%	7300	15				4.0	13	39	130	14.5	2.0	6
721	245	5040	6300	3140	9				80	54	28	28	4.36	6.0	5
722	875	6720	5700	3980	9				800	9	54	18	5.1	1.0	3
723	330	5720	4940	1830	6				43	7	57	16	4.88	3.0	3
724	95	700	7600	7200	6	-0.05	-4	34	40						
725	105	3630	4330	1.53%	4				8.5	14	25	22	8.4	3.0	5
726	900	1.15%	8500	7800	14	-0.05	16	65	80						

Figure 61. Analytical results for the wall rock to the west of the southern Linda Vein outcrop.



Sample	Cu	Pb	Zn	Mn	Ag	Au	Sb	Sn	As	Ni	Co	Cd	Fe	Bi	Cr
741	300	100	1550	115	3	-0.05	10	70	2650						
742A	230	310	4300	300	1	-0.05	8	60	70						
743	165	106	217	660	9				440	3	31	2	2.72	2.5	1

simple. The arsenic and copper contents appear to decrease away from the vein, but the manganese and silver contents increase. Lead and zinc appear to reach a maximum 5 m west of the edge of the waterfall which was assumed to be the edge of the vein. Gold is again not present, but the tuffs contain some tin (60-70 ppm). Bismuth and antimony are present only in small amounts.

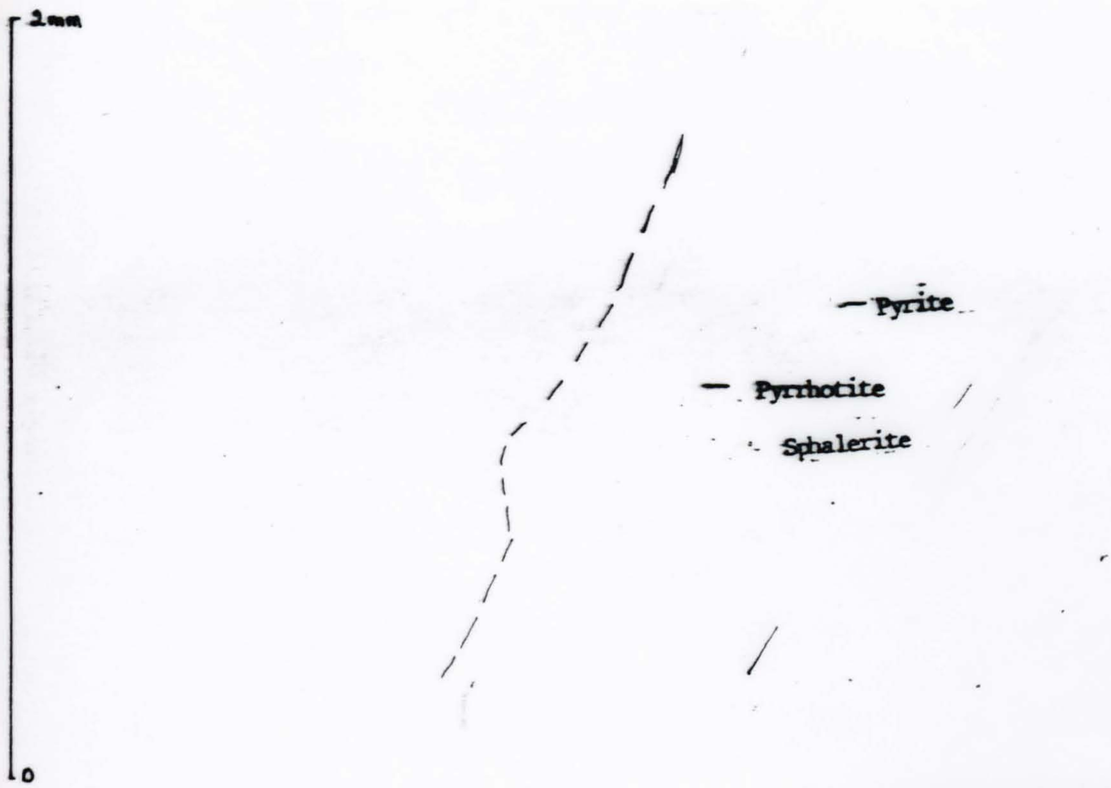
The northern outcrop of the vein has a more obvious quartz reef as part of the mineralisation, but generally the mineral content is lower in the massive quartz than in other samples. The correlation between the different elements is not as high, but most elements show the same general distribution pattern. The amounts of iron, cadmium and zinc are much higher in the footwall, higher in the hangingwall, and low in the central quartz reef and quartz kaolin bands. Manganese, lead and cobalt show a similar pattern, though the largest amounts occur in the hangingwall. In addition the footwall part of the quartz reef is also slightly enriched. Manganese shows a similar pattern, except that the largest concentration occurs slightly west of the hangingwall. Arsenic again appears to have a negative correlation with many of the other elements, most occurring near the footwall of the quartz reef. Nickel shows a distribution unrelated to the other elements, with the largest amounts occurring in the footwall of the mineralised zone. Silver is higher at the edges of the mineralised zone. Much of the published information about the Mangani area contains only information about grades and widths of the veins, with no indication of the value of the wall rock. This again suggests that such information is only of limited value, as the wall rock and edges of the veins may contain higher quantities of precious metals than the actual quartz reef. Generally the analytical results for the northern vein outcrop are similar to those for the vein outcrop 20m further south.

4.11.5 Petrology

19 thin sections of sulphidic and gangue material were examined from this vein.

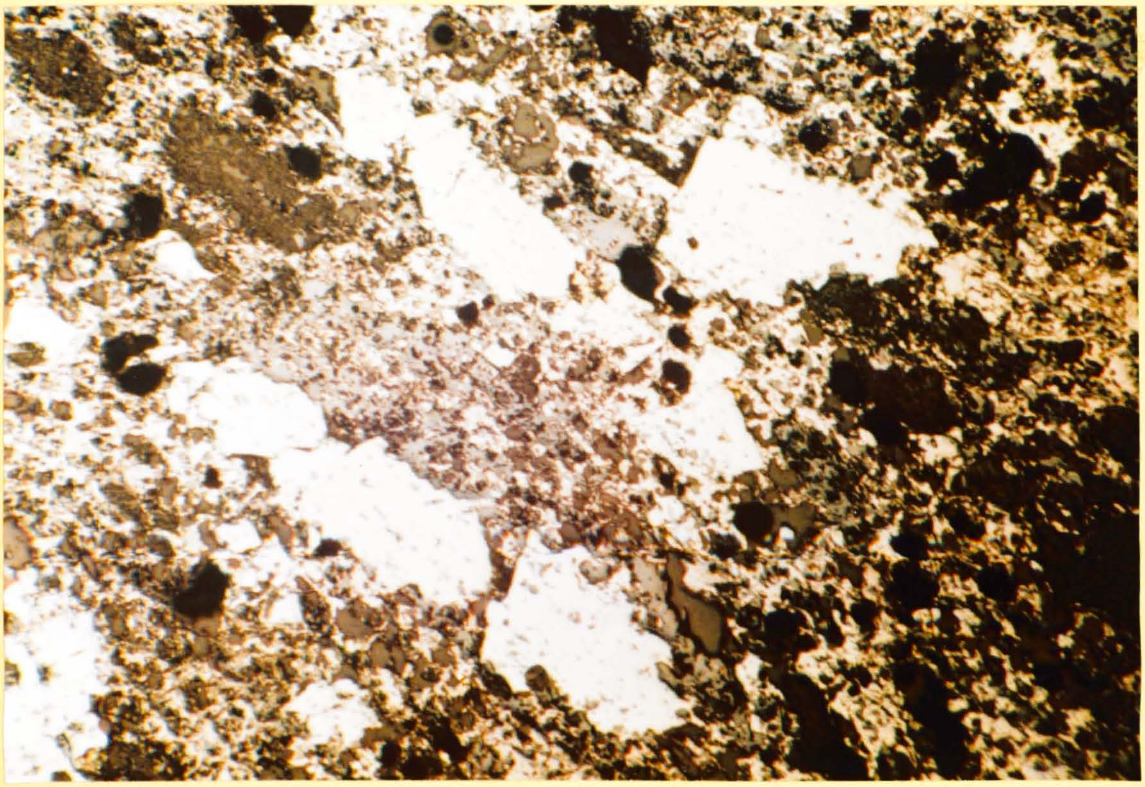
The matrix of the vein consists partially of altered volcanics, with the outlines of feldspars being

Plate 18



a. Photomicrograph of a polished section from the Linda Vein (L16), showing early finely brecciated pyrrhotite and sphalerite veined by later pyrite, and redeformed.

b. Photomicrograph of a polished section from the Linda Vein (L16), showing details of the finely brecciated ore, and augen structures.



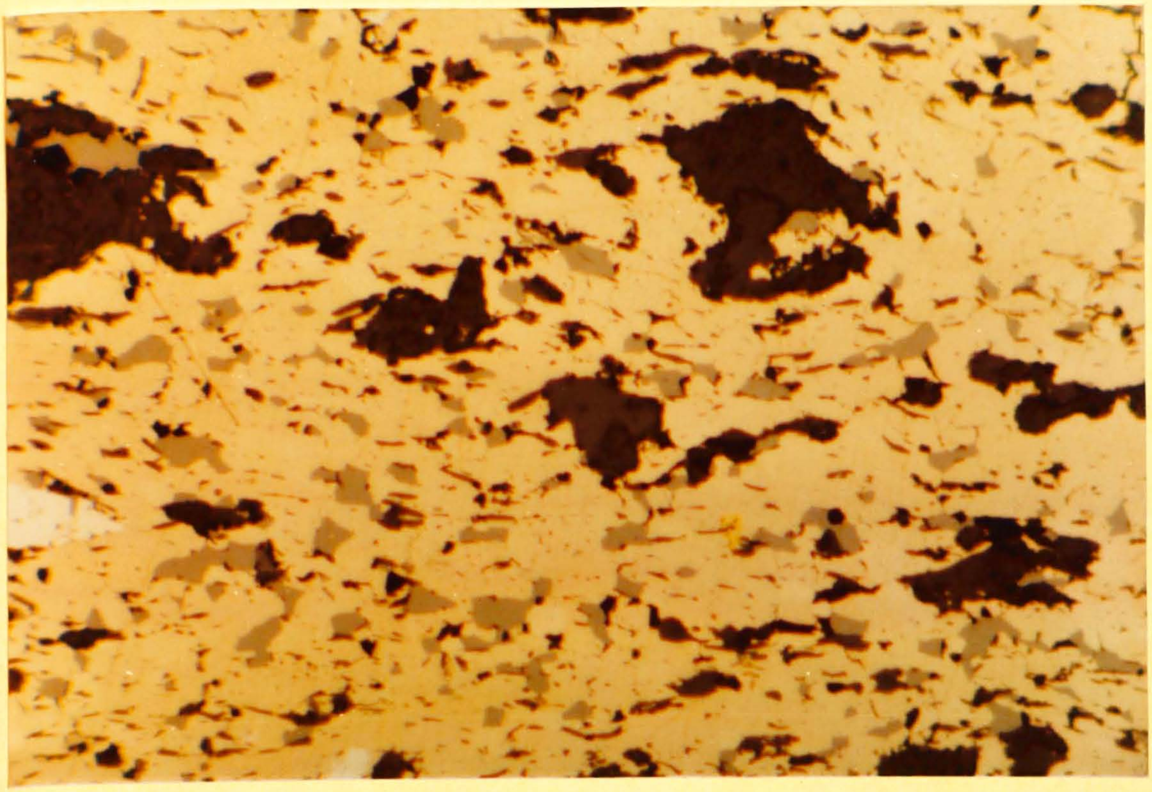
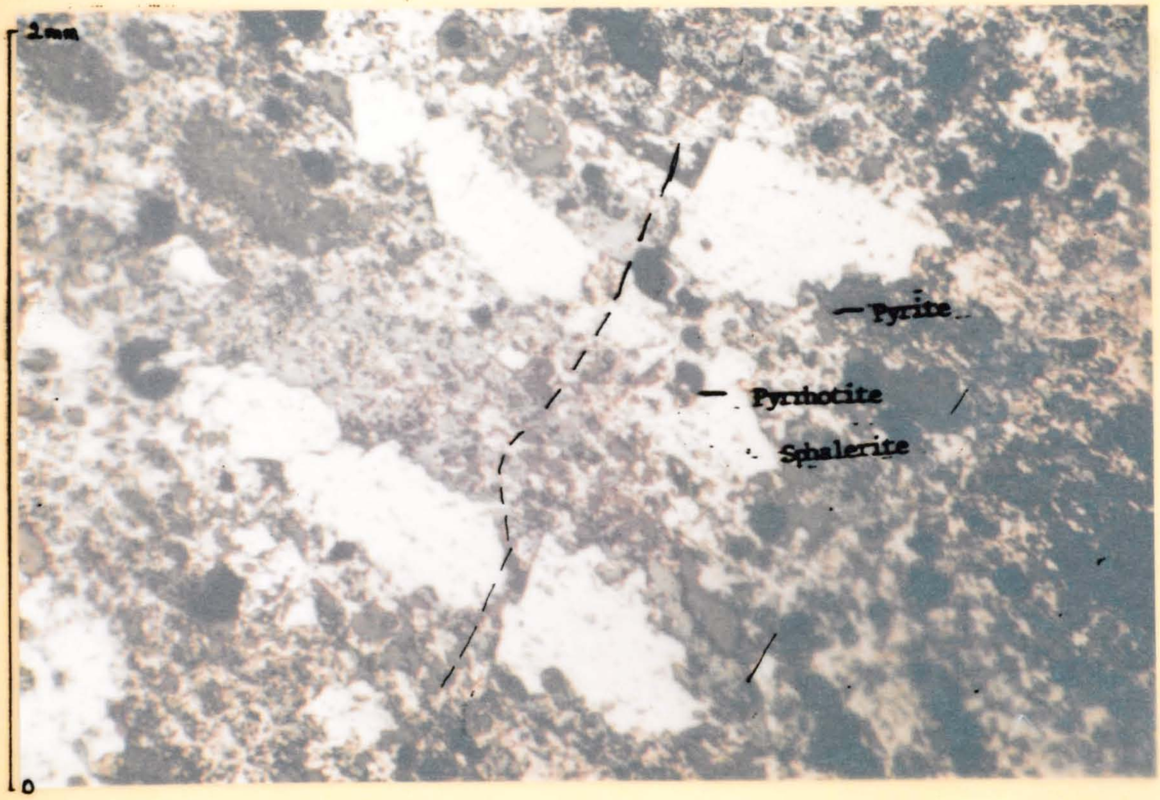
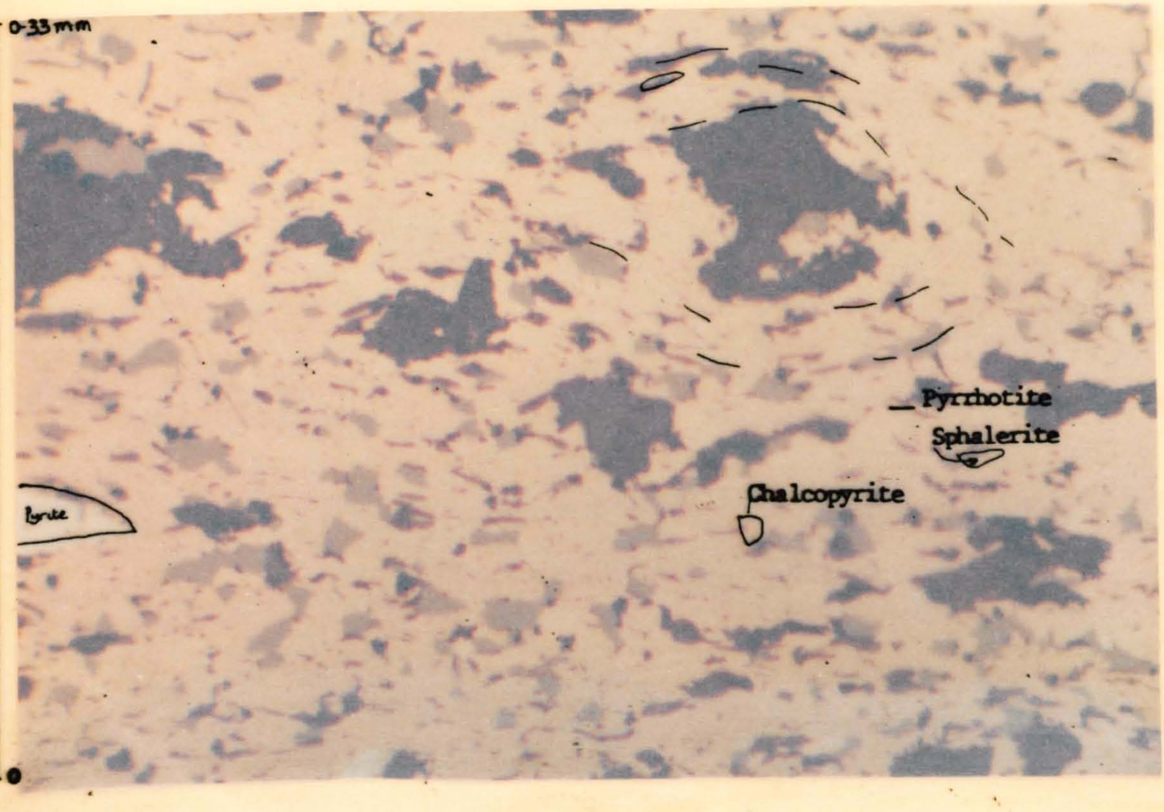


Plate 18

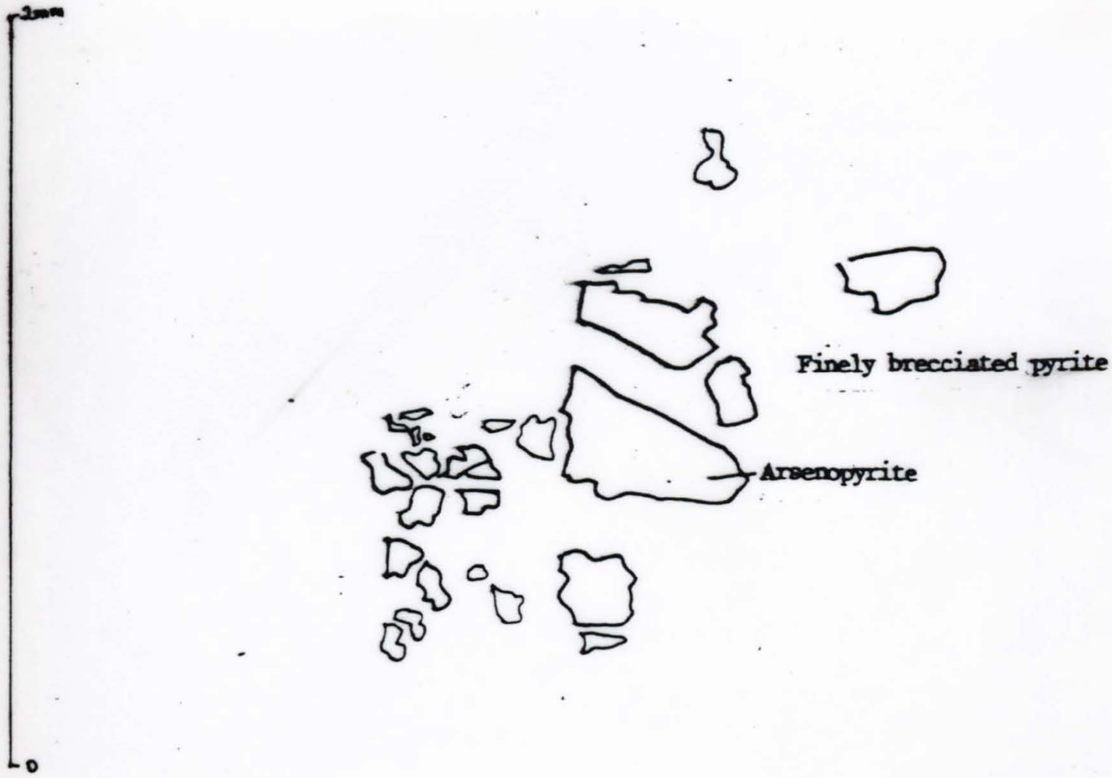


a. Photomicrograph of a polished section from the Linda Vein (L16), showing early finely brecciated pyrrhotite and sphalerite veined by later pyrite, and redeformed.

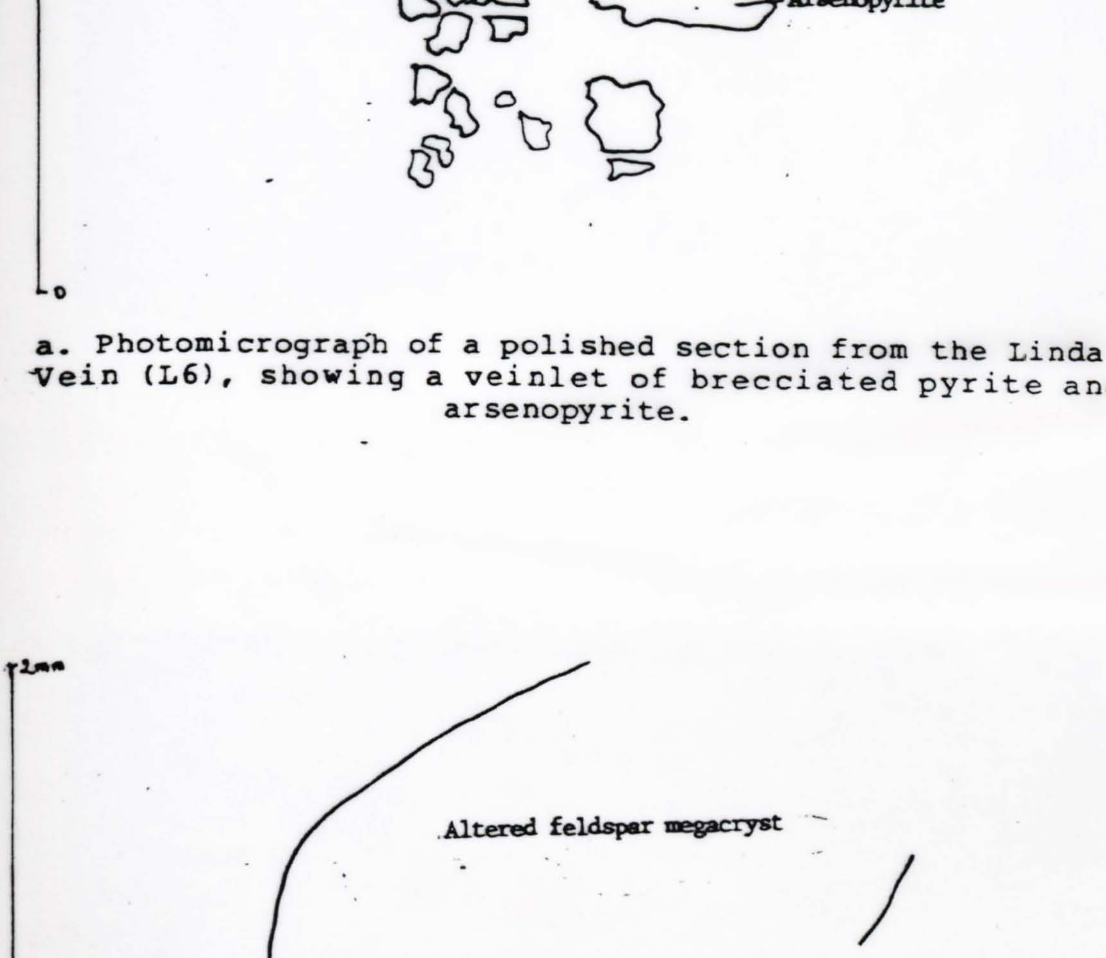


b. Photomicrograph of a polished section from the Linda Vein (L16), showing details of the finely brecciated ore, and augen structures.

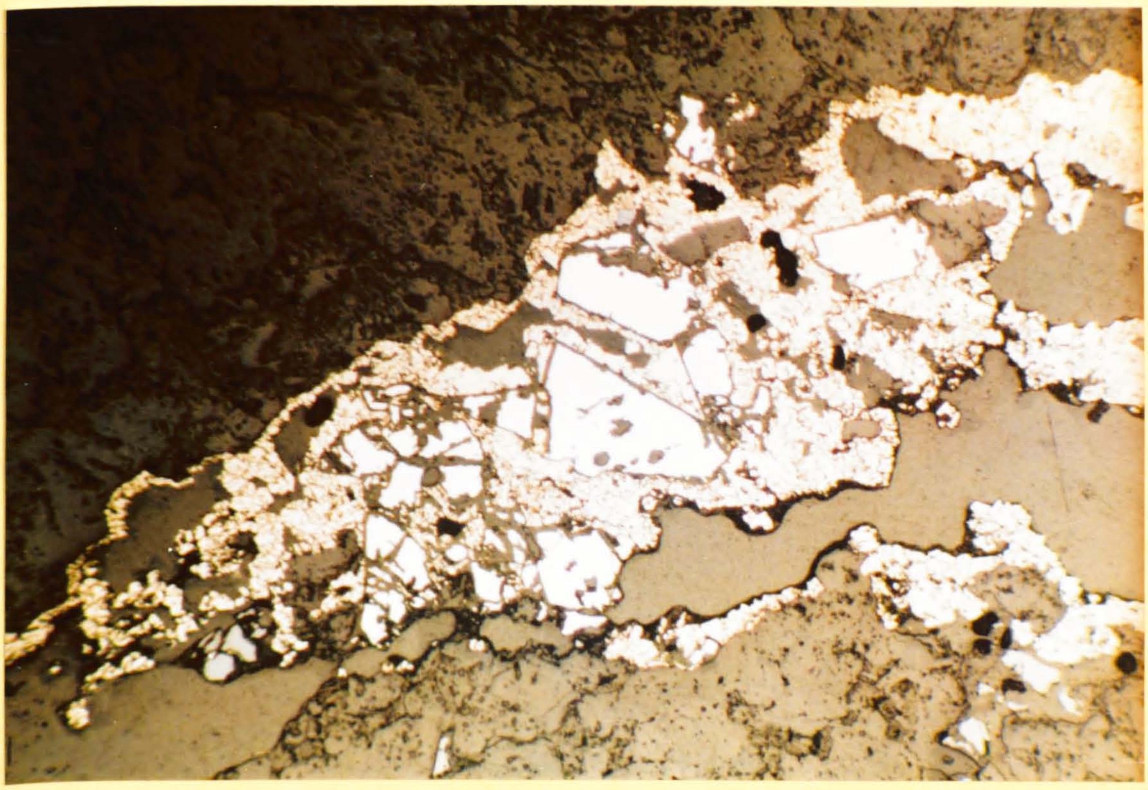
Plate 19



a. Photomicrograph of a polished section from the Linda Vein (L6), showing a veinlet of brecciated pyrite and arsenopyrite.



b. Photomicrograph of a thin section from the Linda Vein (L8), showing the presence of altered feldspar in gangue material.



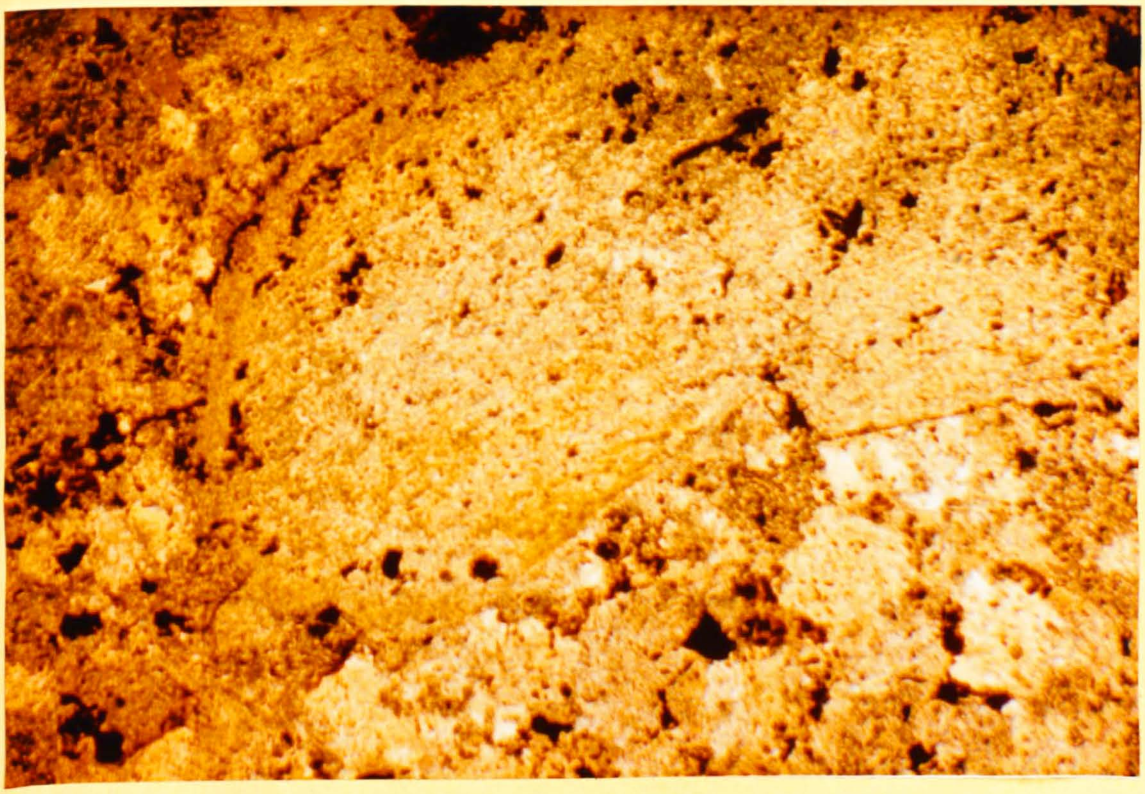
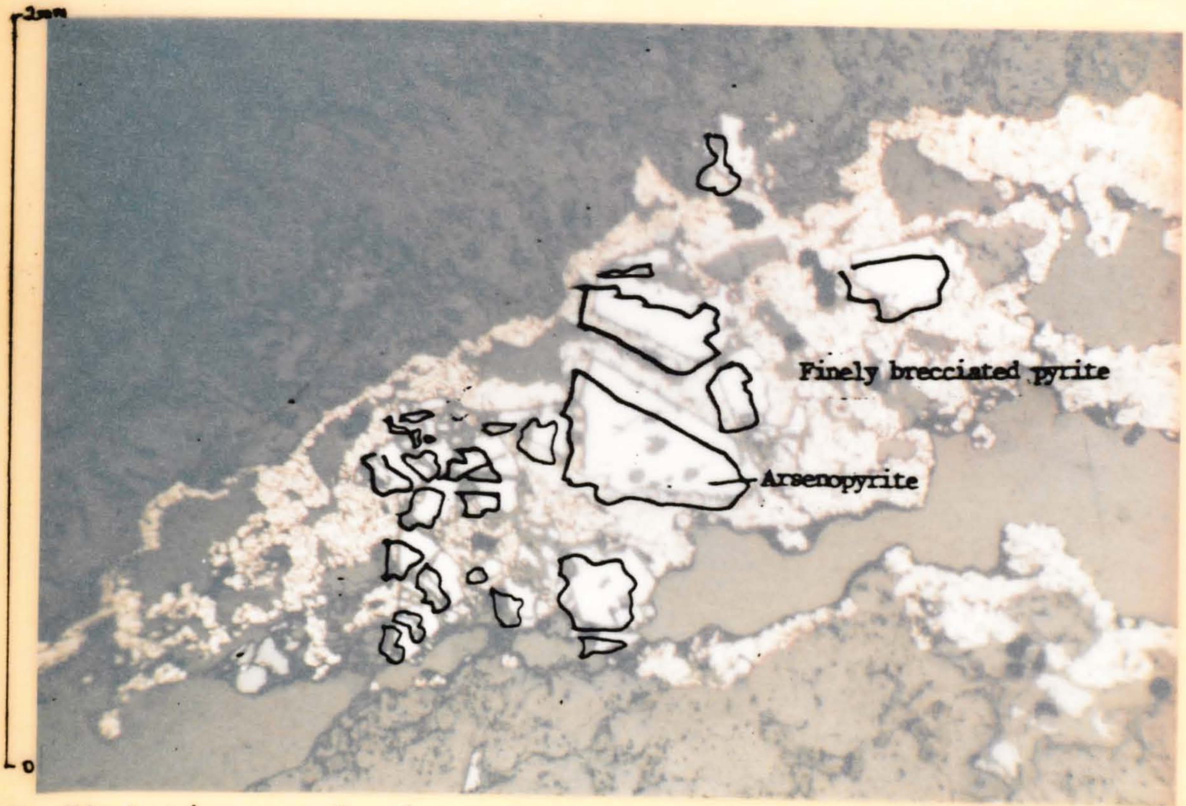


Plate 19



a. Photomicrograph of a polished section from the Linda Vein (L6), showing a veinlet of brecciated pyrite and arsenopyrite.

b. Photomicrograph of a thin section from the Linda Vein (L8), showing the presence of altered feldspar in gangue material.

recognisable in the least altered specimens (Plate 19b). Other components include clasts of Telisa Formation mudstone in a breccia with volcanic components. Like other veins little primary space filling quartz is present, though thin cross cutting quartz veinlets with very well shaped crystals do occur. Most specimens are partially or totally replaced by quartz and carbonate. Fluid inclusions are abundant, many appearing to be primary. Many inclusions contain a gas bubble, and a few contain a daughter mineral.

Early arsenopyrite occurs in veinlets of crushed pyrite (Plate 19a). More normal pyrite grains with small sphalerite inclusions, and blebs and veinlets of sphalerite with "chalcopyrite disease" are also present. The last stage of pyrite deposition occurs as large crystals in veinlets, the pyrite showing growth zoning, and containing no inclusions.

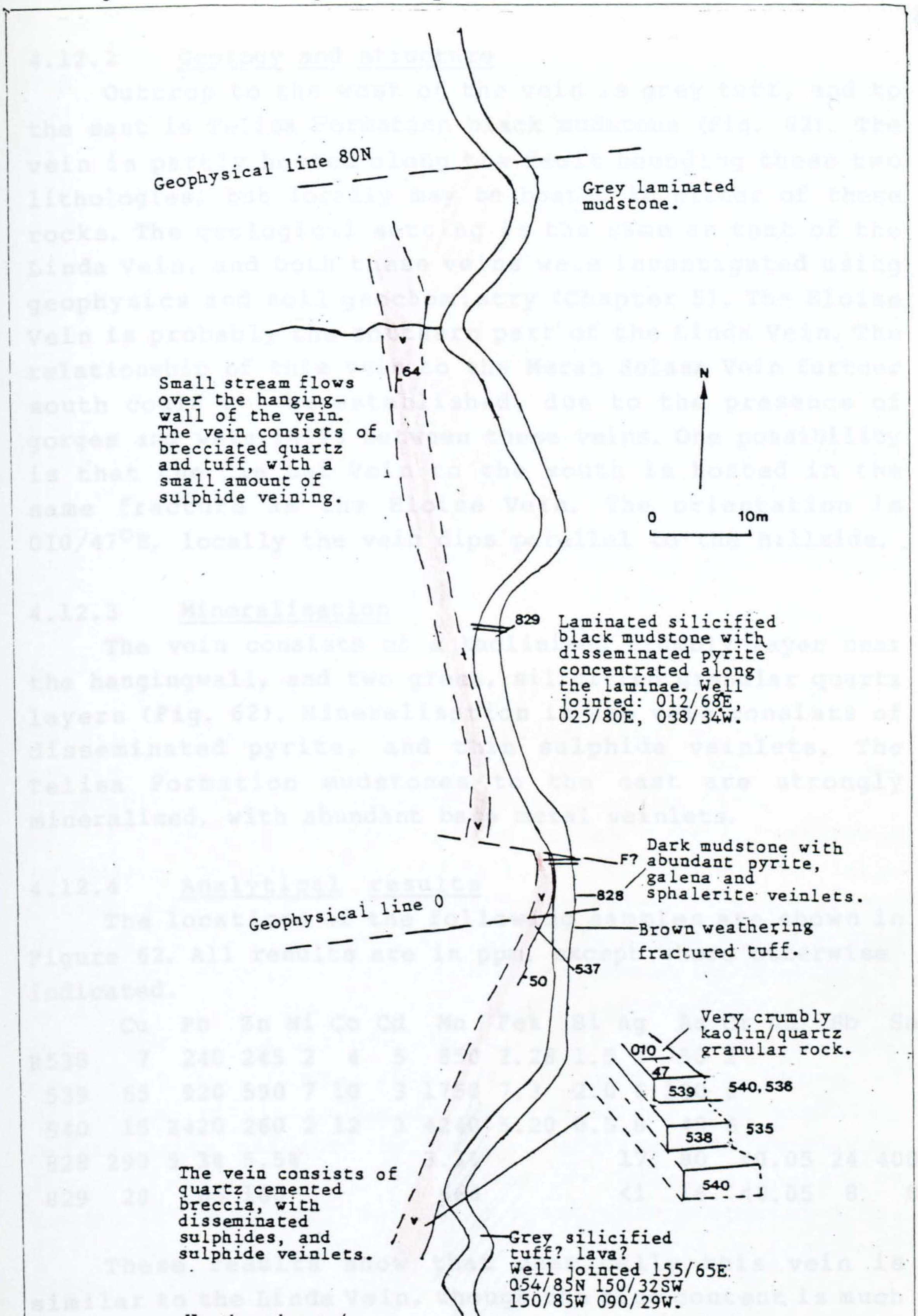
The massive sulphide specimens (Ma R715, Ma R716) consist of pyrite in very finely brecciated pyrrhotite and sphalerite, veined by later pyrite (Plate 18a), and in some cases by chalcopyrite. This material has then undergone further brecciation. Plate 18b shows the finely granulated nature of this material, and shows "augen" structures around resistant quartz grains. Plate 17b shows the early brecciated material being partly replaced by arsenopyrite, which is itself brecciated, with spaces being infilled with quartz.

4.12 Eloise Vein

4.12.1 Introduction

This vein outcrops in the A. Galangang Kanan, to the east of Bukit Bulat. The vein occurs to the south of the Linda Vein, and to the north of the gorges and waterfalls marking the edge of the Mangani Graben. The Eloise Vein was discovered during the present investigation.

Figure 62. Geological map of the Eloise Vein area.



4.12.2 Geology and structure

Outcrop to the west of the vein is grey tuff, and to the east is Telisa Formation black mudstone (Fig. 62). The vein is partly hosted along the fault bounding these two lithologies, but locally may be hosted in either of these rocks. The geological setting is the same as that of the Linda Vein, and both these veins were investigated using geophysics and soil geochemistry (Chapter 5). The Eloise Vein is probably the southern part of the Linda Vein. The relationship of this vein to the Merah Selasa Vein further south could not be established, due to the presence of gorges and waterfalls between these veins. One possibility is that the Cie Lei Vein to the south is hosted in the same fracture as the Eloise Vein. The orientation is 010/47^{o}E, locally the vein dips parallel to the hillside.

4.12.3 Mineralisation

The vein consists of a kaolinised crumbly layer near the hangingwall, and two green, silicified granular quartz layers (Fig. 62). Mineralisation in the vein consists of disseminated pyrite, and thin sulphide veinlets. The Telisa Formation mudstones to the east are strongly mineralised, with abundant base metal veinlets.

4.12.4 Analytical results

The locations of the following samples are shown in Figure 62. All results are in ppm, except where otherwise indicated.

	Cu	Pb	Zn	Ni	Co	Cd	Mn	Fe%	Bi	Ag	As	Cr	Au	Sb	Sn
R538	7	240	245	2	4	5	850	2.28	1.5	2	50	2			
539	65	920	590	7	10	3	1750	7.3	2.0	6	130	6			
540	15	2420	260	2	12	3	4240	5.20	0.5	8	40	6			
828	290	5.3%	5.5%				3.3%			17	80		<0.05	24	400
829	28	85	160				660			<1	16		<0.05	8	8

These results show that chemically this vein is similar to the Linda Vein, though the zinc content is much lower. The arsenic content is not as high as the southern part of the Linda Vein, but similar to the northern part.

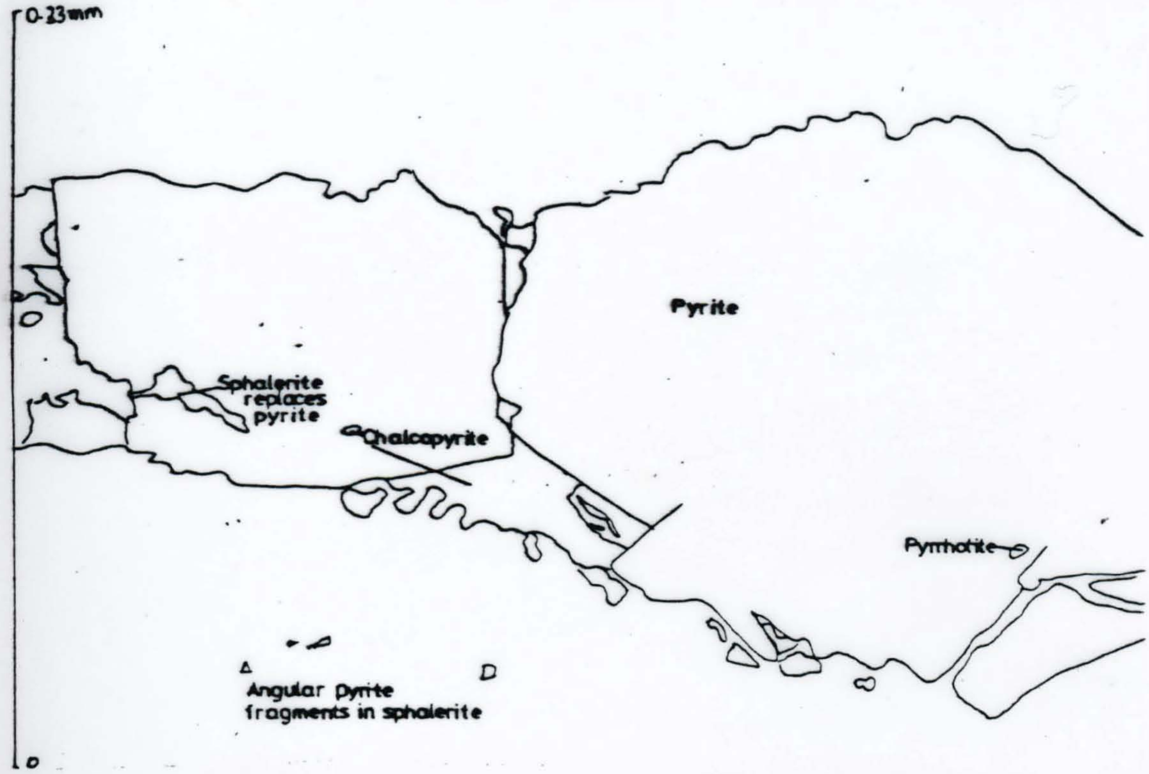
To the east of the vein, the dark mudstones are conspicuously veined with base metal sulphides, and the analytical results for a grab sample (R828) show a much higher element content in this material than in the quartz vein itself. Further to the north, R829 is a sample of dark laminated mudstone, with abundant disseminated pyrite parallel to the laminations. The analytical results show that most of the sulphide is pyrite, and though the element content is moderately high, and the sample collected only a short distance from the vein, it is not as high as the sample collected further to the south. One explanation for the lack of mineralisation in the more northerly mudstone is that it is far more silicified, and examination of thin sections of altered rocks has shown that the silicification and pyritisation often preceded the carbonate alteration, which appears to accompany the mineralisation. The silicification may have reduced the porosity and permeability of the mudstone, and prevented the penetration of the mineralising fluids.

4.12.5 Petrology

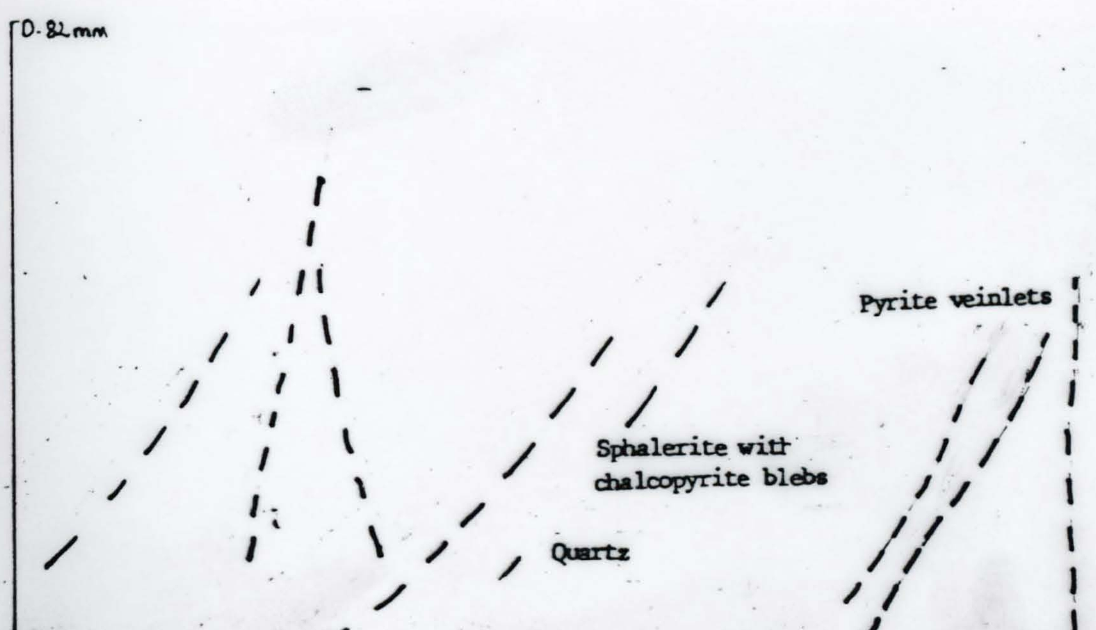
Four samples from this vein were examined in thin section. Early veinlets of pyrite contain very small angular arsenopyrite, and pyrrhotite inclusions. A second generation of pyrite veinlets cross cut the first.

The gangue consists of tuffaceous material replaced by quartz and carbonate, with later replacement by large quartz grains. Small pyrrhotite inclusions are sometimes present in quartz crystals. Pyrite is sometimes bordered by chalcopyrite, which is itself rimmed by sphalerite (Plate 20a). Sphalerite also locally replaces pyrite. some specimens show a texture similar to that seen in the Merah Selasa Vein (Plate 20b), with very thin bands of brecciated pyrite in sphalerite, which has been annealed, before being affected by post mineralisation fracturing. Weathering has resulted in pyrite being replaced by haematitic material, which has sometimes penetrated along fractures and grain boundaries to give a feathery appearance.

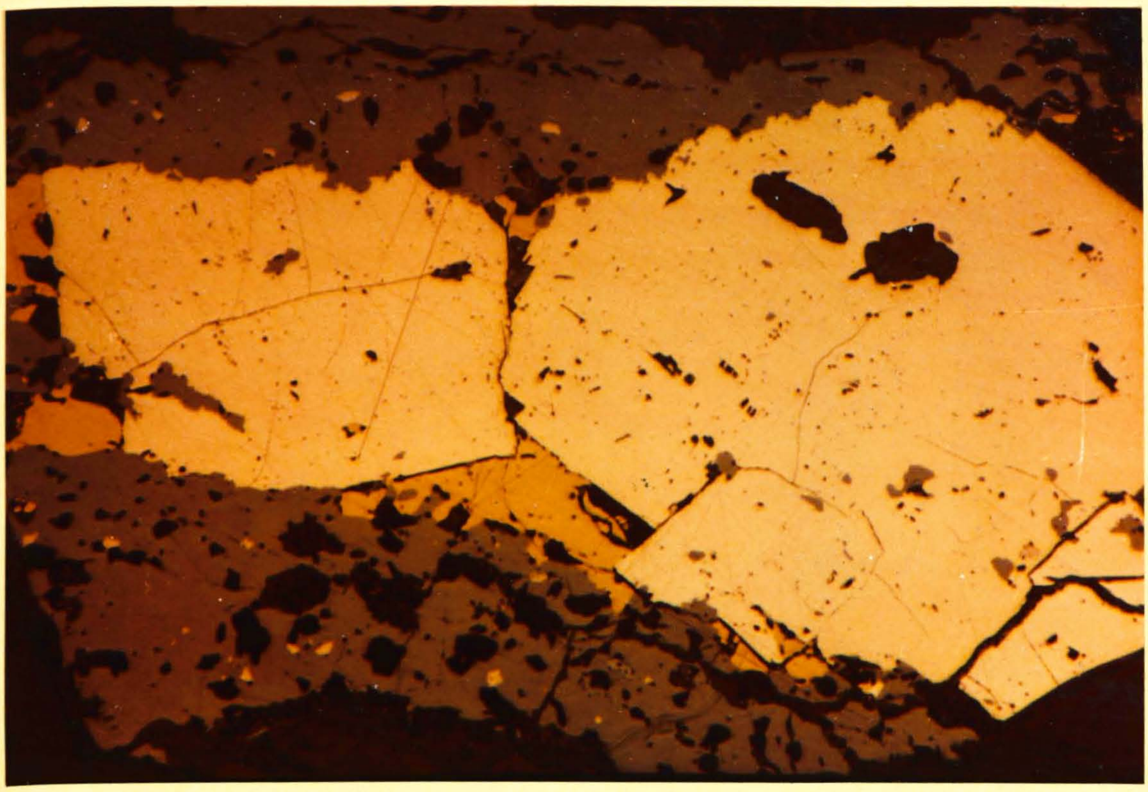
Plate 20



a. Photomicrograph of a polished section from the Eloise Vein (El), showing rimming of a pyrite vein by later chalcopyrite and sphalerite.



b. Photomicrograph of a polished section from the Eloise Vein (El), showing veinlets of pyrite in sphalerite affected by several periods of fracturing.



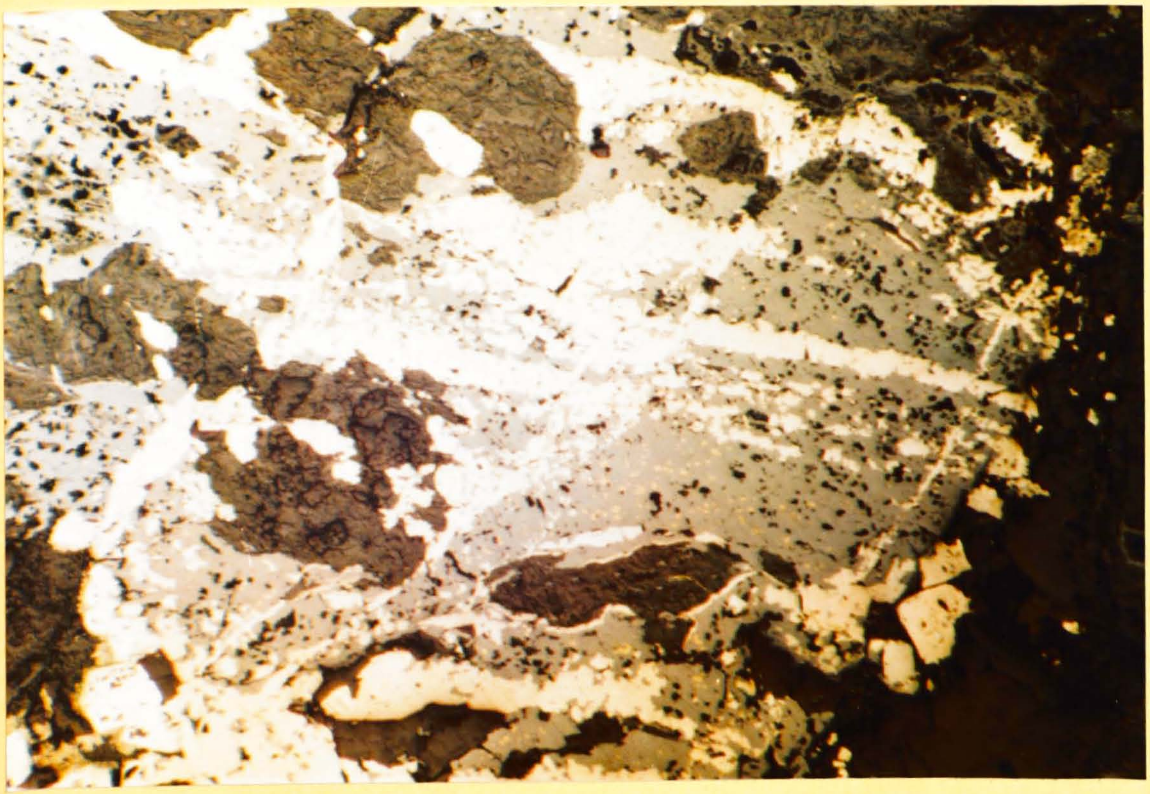
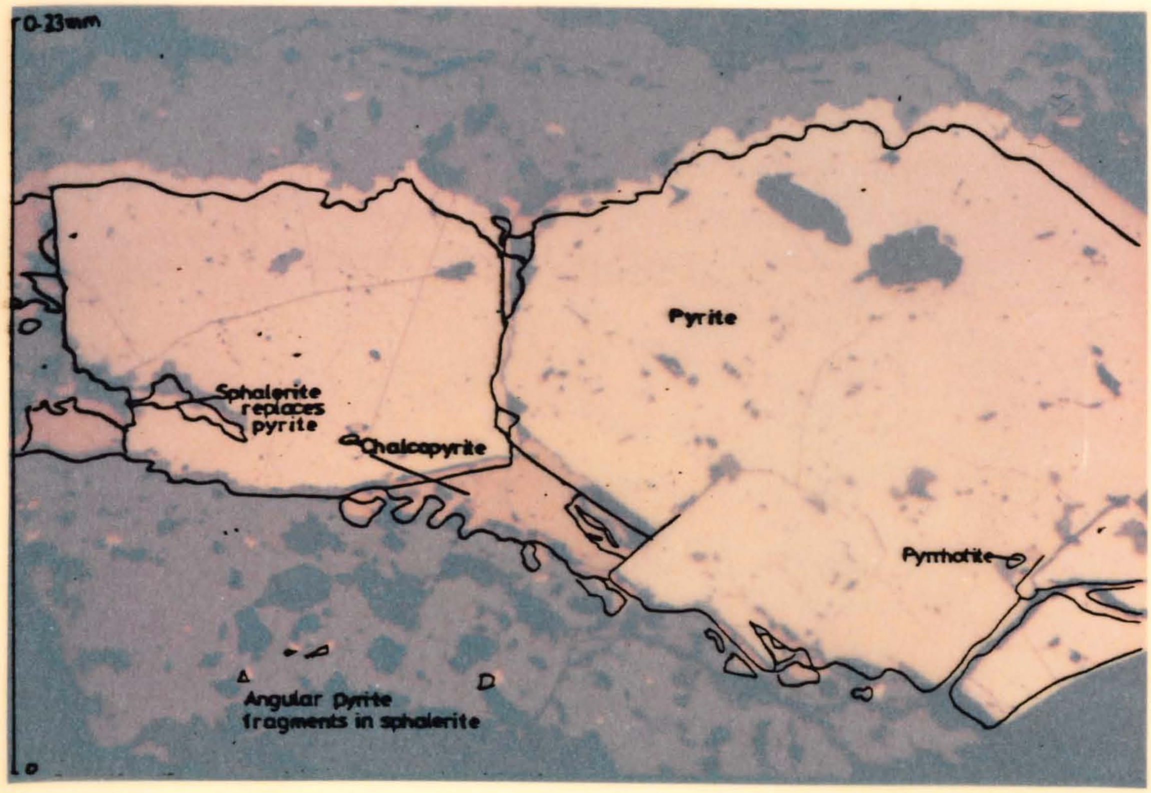
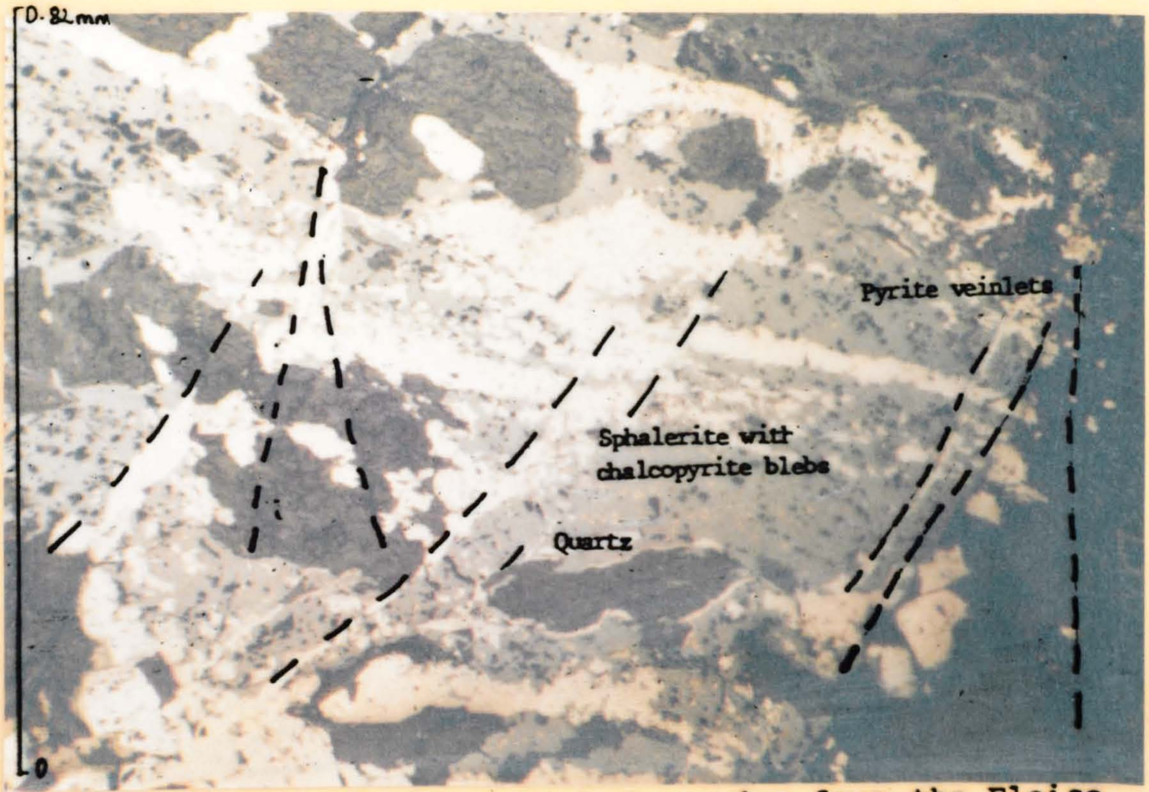


Plate 20



a. Photomicrograph of a polished section from the Eloise Vein (E1), showing rimming of a pyrite vein by later chalcopyrite and sphalerite.



b. Photomicrograph of a polished section from the Eloise Vein (E1), showing veinlets of pyrite in sphalerite affected by several periods of fracturing.

4.13 Merah Selasa Vein

4.13.1 Introduction

This vein is located in the Galanggang Kanan stream, near the edge of the Mangani Graben, and was discovered during the present investigation. Initially only the Merah Selasa Cross Vein was recognised, as the main part of the Merah Selasa Vein outcropping in the river further north has the appearance of highly silicified pyritised quartzite, and quartzite often outcrops just to the north of the Mangani Graben.

4.13.2 Geology

Figure 63 shows a detailed map of the area, though very little outcrop is present. Enclosure 2 shows the geology of the whole Mangani area, and shows that Telisa Formation sediments outcrop to the east of this vein outcrop. To the west of this vein volcanic rocks occur.

4.13.3 Structure

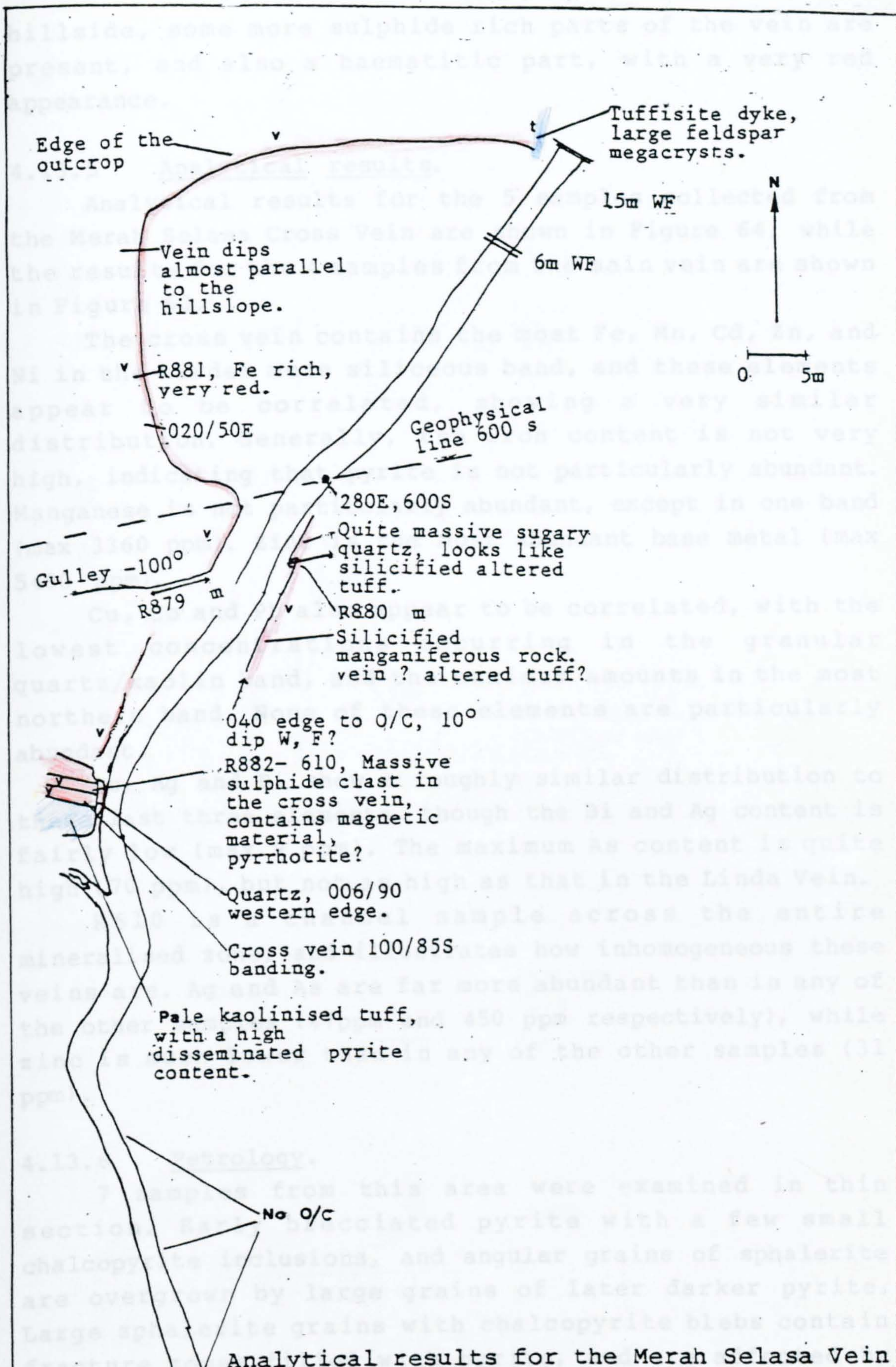
The main vein dips almost parallel to the hillslope, trending approximatey 040/35^{o}E. A cross vein, oriented 100/85^{o}S cuts across the vein in the south, but is itself bounded by an 006/vertical fault. The main vein also seems to be cut by a fault along the river, trending approximately 040^{o}.

4.13.4 Mineralisation

The cross vein consists of a number of silicified and kaolinised bands, bounded on the southern side by altered tuff. The wallrock on the north side is not exposed, but vein material from the main vein outcrops only a metre further north. Some of the kaolinised bands contain clasts of massive sulphide, which contain magnetic pyrrhotite, so that measurements of the orientations of these veins may not be very accurate.

The main vein exposed in the river, as previously stated, consists mainly of quartz, with a granular appearance, looking very similar to silicified quartzite. This material contains disseminated pyrite, and thin sulphide veinlets. To the west of the river, up on the

Figure 63. Geological map of the Merah Selasa Vein area.



Analytical results for the Merah Selasa Vein

Sample	Cu	Pb	Zn	Mn	Ag	Au	Sb	Sn	As ppm
879	32	36	210	230	2	-0.05	-4	28	6
880	500	110	700	1350	4	-0.05	-4	28	22
881	480	75	430	105	7	-0.05	-4	-4	28
882	700	1950	6.8%	9800	13	-0.05	-4	90	55

hillside, some more sulphide rich parts of the vein are present, and also a haematitic part, with a very red appearance.

4.13.5 <u>Analytical results</u>.

Analytical results for the 5 samples collected from the Merah Selasa Cross Vein are shown in Figure 64, while the results for the 4 samples from the main vein are shown in Figure 63.

The cross vein contains the most Fe, Mn, Cd, Zn, and Ni in the harder more siliceous band, and these elements appear to be correlated, showing a very similar distribution. Generally, the iron content is not very high, indicating that pyrite is not particularly abundant. Manganese is not particularly abundant, except in one band (max 3360 ppm). Zinc is the most abundant base metal (max 5480 ppm).

Cu, Co and Pb also appear to be correlated, with the lowest concentrations occurring in the granular quartz/kaolin band, and the maximum amounts in the most northern band. None of these elements are particularly abundant.

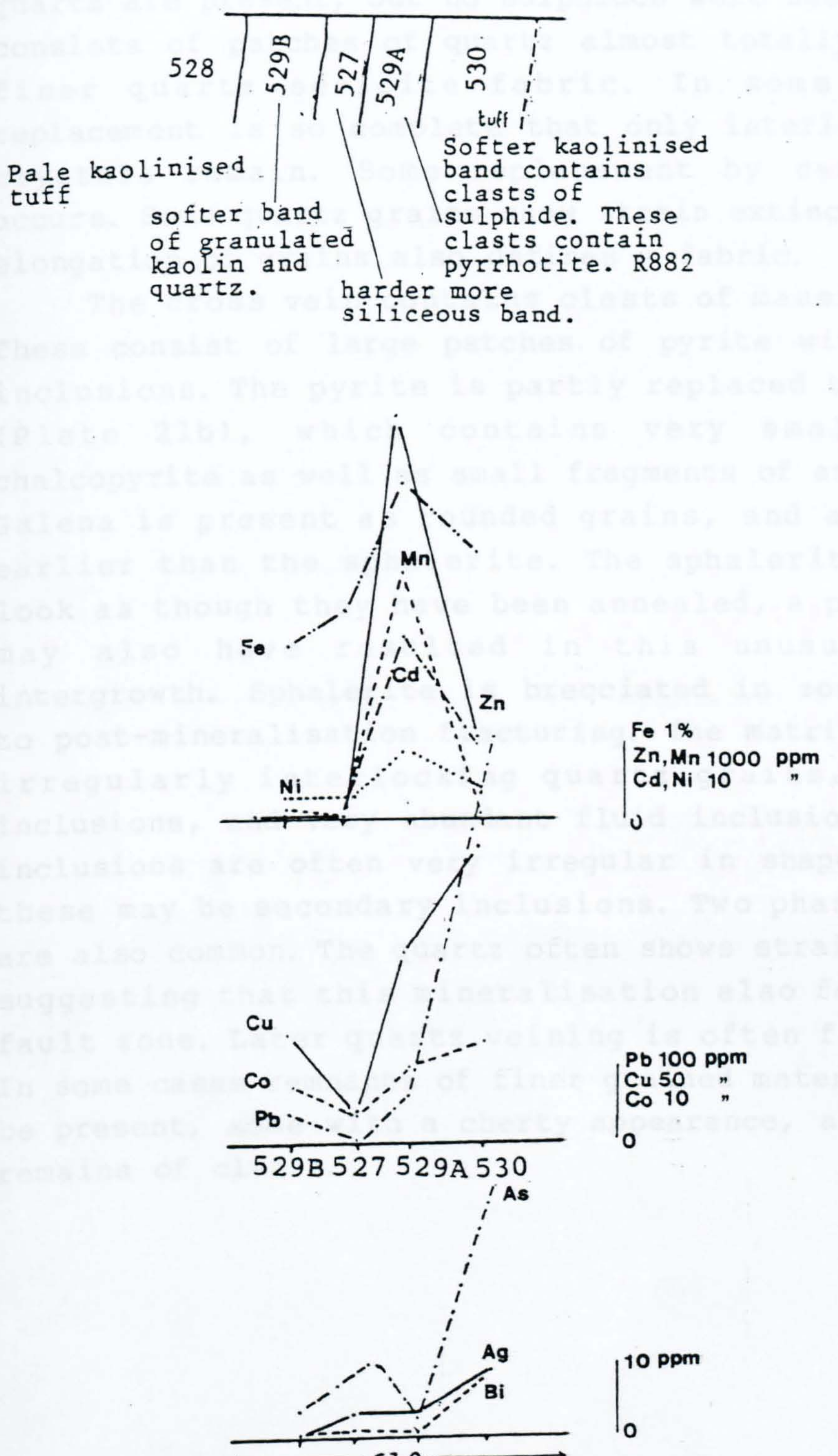
As, Ag and Bi show a roughly similar distribution to these last three elements, though the Bi and Ag content is fairly low (max 9 ppm). The maximum As content is quite high (70 ppm), but not as high as that in the Linda Vein.

R610 is a channel sample across the entire mineralised zone, and illustrates how inhomogeneous these veins are. Ag and As are far more abundant than in any of the other samples (47ppm and 450 ppm respectively), while zinc is much lower than in any of the other samples (31 ppm).

4.13.6 <u>Petrology</u>.

7 samples from this area were examined in thin section. Early brecciated pyrite with a few small chalcopyrite inclusions, and angular grains of sphalerite are overgrown by large grains of later darker pyrite. Large sphalerite grains with chalcopyrite blebs contain fracture zones filled with pyrite, and are affected by later fracture zones (Plate 21a). Such material occurs as clasts in a breccia. Bands of brecciated quartz,

Figure 64. Analytical results for the Merah Selasa Cross Vein.

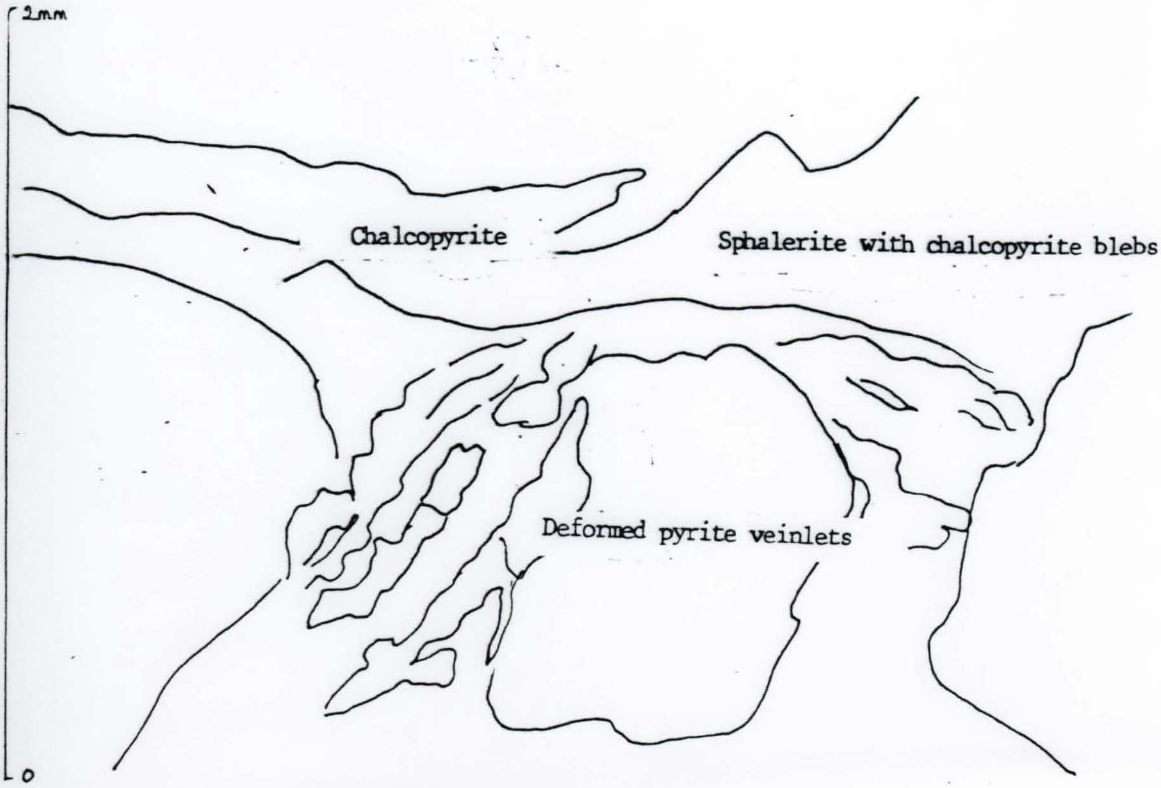


Sample	Cu	Pb	Zn	Ni	C	Cd	Mn	Fe%	Bi	Ag	As	Cr
527	20	3	47	3	4	1	68	2.08	1.0	3	22	2
529A	129	66	5480	9	11	25	3360	4.51	0.5	3	6.0	4
529B	74	44	75	3	8	1	170	2.32	0.5	1	8.5	1
530	200	560	1100	4	14	10	96	3.60	9.0	9	70	1
610	36	260	31	1	6	1	670	2.4	0.5	47	450	1

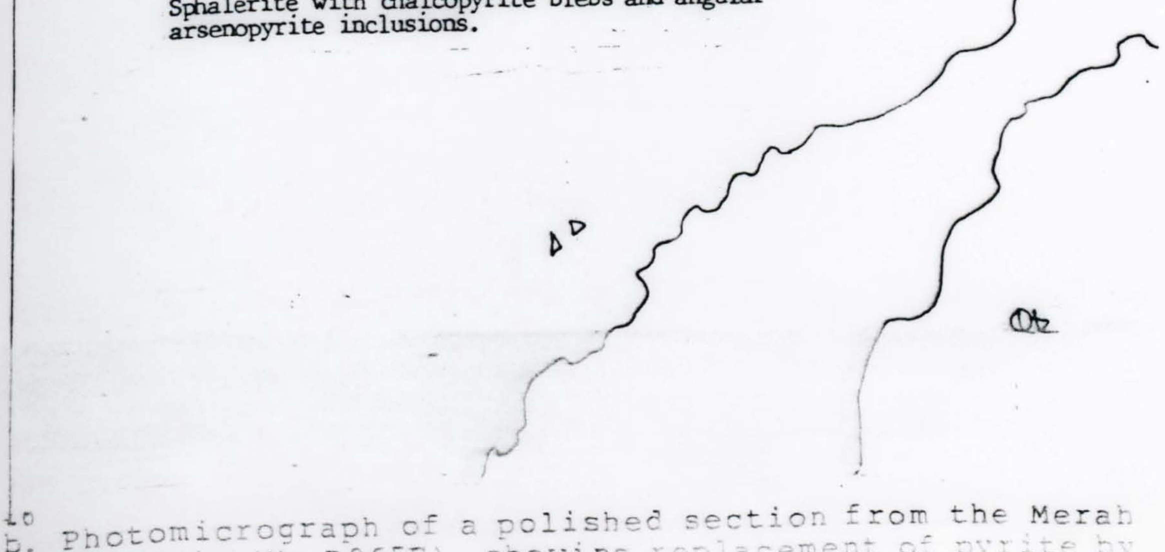
sphalerite and pyrite also occur. The haematitic zone mentioned earlier consists partly of colloform haematite, and partly of spongy haematite. A few irregular patches of quartz are present, but no sulphides were seen. The matrix consists of patches of quartz almost totally replacing a finer quartz-sericite fabric. In some places the replacement is so complete that only interlocking quartz crystals remain. Some replacement by carbonate also occurs. Some quartz grains show strain extinction, and the elongation of grains also defines a fabric.

The cross vein contains clasts of massive sulphide. These consist of large patches of pyrite with pyrrhotite inclusions. The pyrite is partly replaced by sphalerite (Plate 21b), which contains very small blebs of chalcopyrite as well as small fragments of angular pyrite. Galena is present as rounded grains, and appears to be earlier than the sphalerite. The sphalerite and pyrite look as though they have been annealed, a process which may also have resulted in this unusually coarse intergrowth. Sphalerite is brecciated in zones, relating to post-mineralisation fracturing. The matrix consists of irregularly interlocking quartz grains, with dusty inclusions, and very abundant fluid inclusions. The fluid inclusions are often very irregular in shape, suggesting these may be secondary inclusions. Two phase inclusions are also common. The quartz often shows strain extinction, suggesting that this mineralisation also formed along a fault zone. Later quartz veining is often finer grained. In some cases remnants of finer grained material appear to be present, some with a cherty appearance, and may be the remains of clasts.

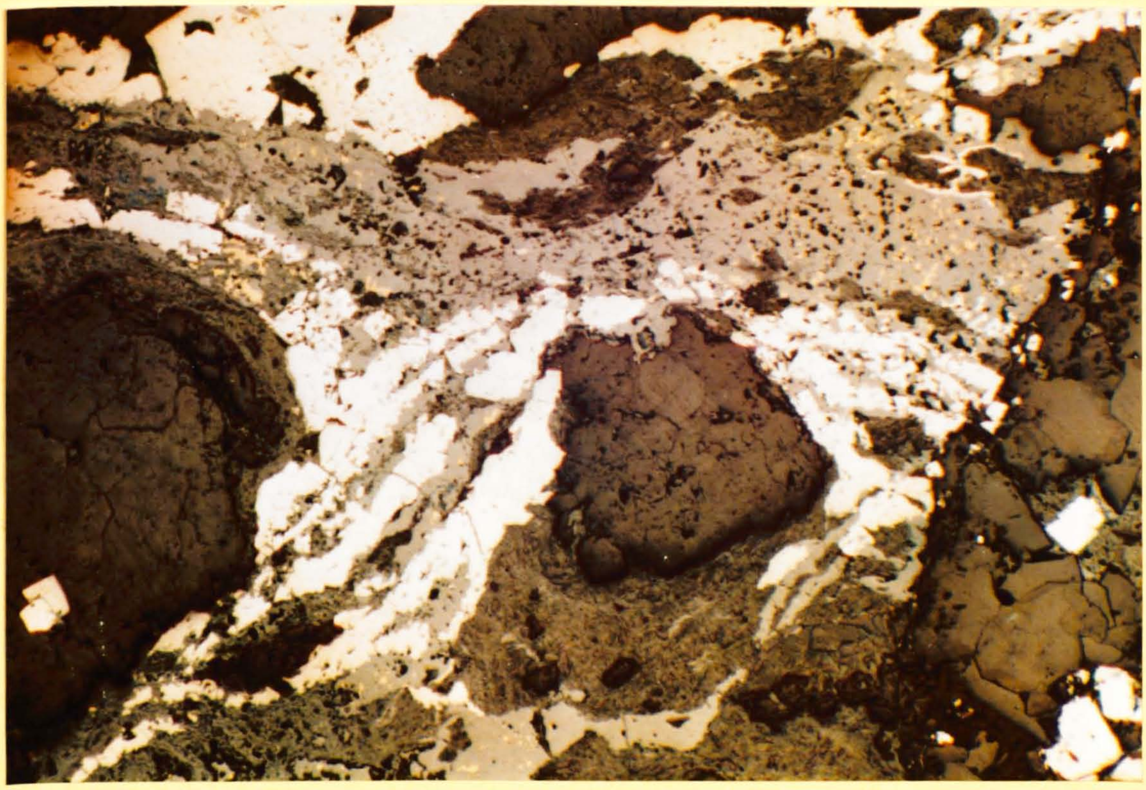
Plate 21



a. Photomicrograph of a polished section from the Merah Selasa Vein (R865B), showing replacement and deformation textures.



b. Photomicrograph of a polished section from the Merah Selasa Vein (Ma R865E), showing replacement of pyrite by Galena.



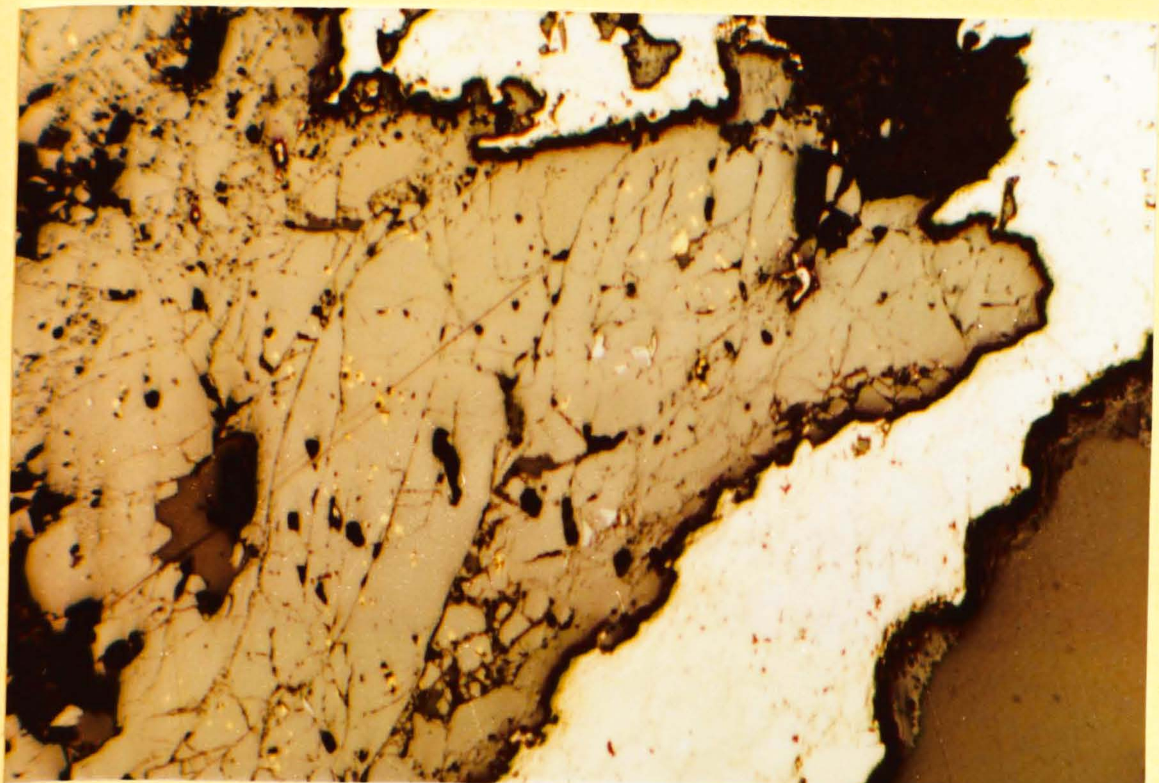
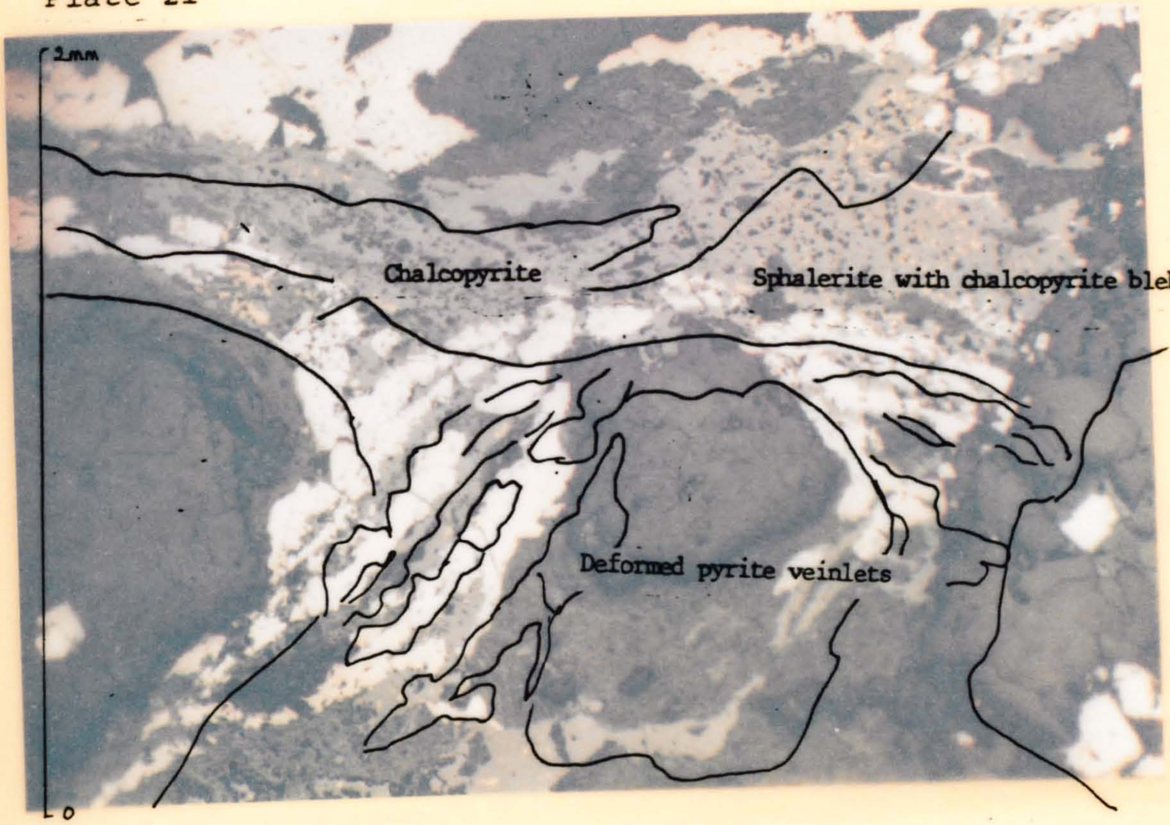
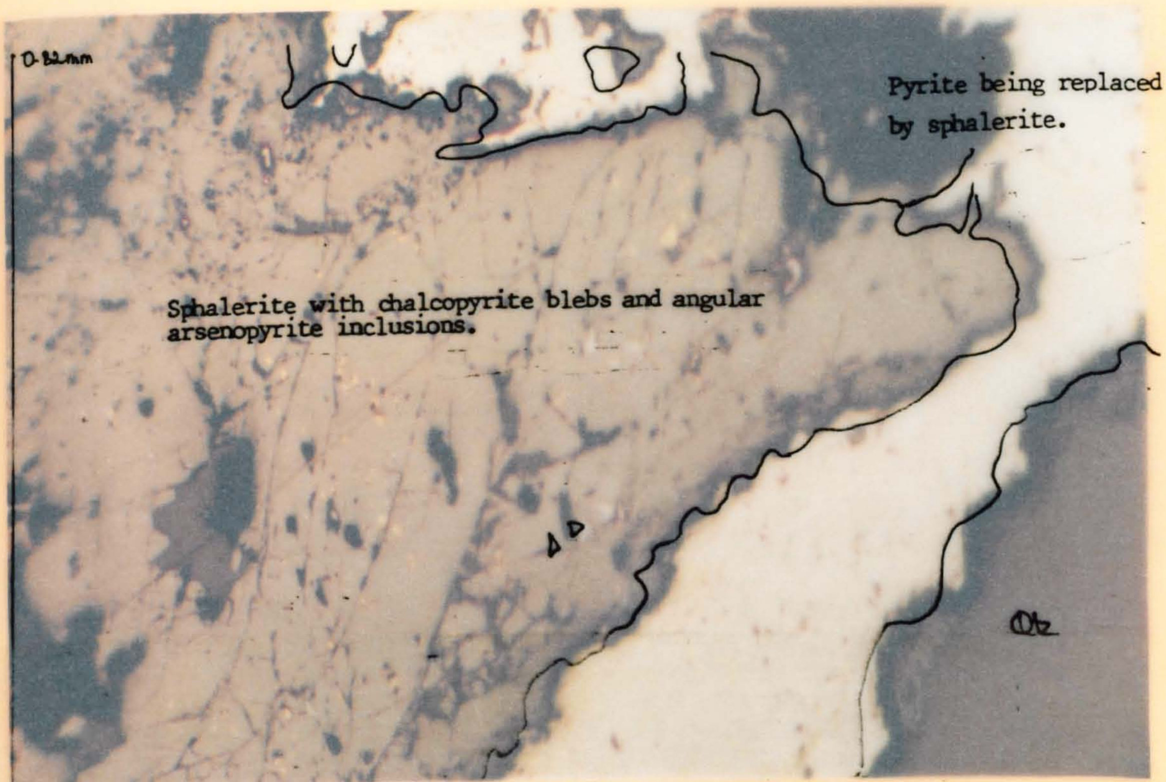


Plate 21



a. Photomicrograph of a polished section from the Merah Selasa Vein (R865B), showing replacement and deformation textures.



b. Photomicrograph of a polished section from the Merah Selasa Vein (Ma R865E), showing replacement of pyrite by Galena.

4.14 Galanggang Black Vein

4.14.1 Introduction.

This vein outcrops in the southern part of the Galanggang Kanan River. The vein was discovered during the present investigation, though in the first field season only a clay band was exposed. Later the river removed a small landslip that had obscured the quartz reef outcrop. The vein has a very high manganese content, and a black appearance.

4.14.2 Geology.

In the immediate vicinity of this vein only volcanics are exposed (Enclosure 2), and the host rock consists of tuff. This vein, and the nearby Cie Lei Vein, are quite near the edge of the Mangani Graben.

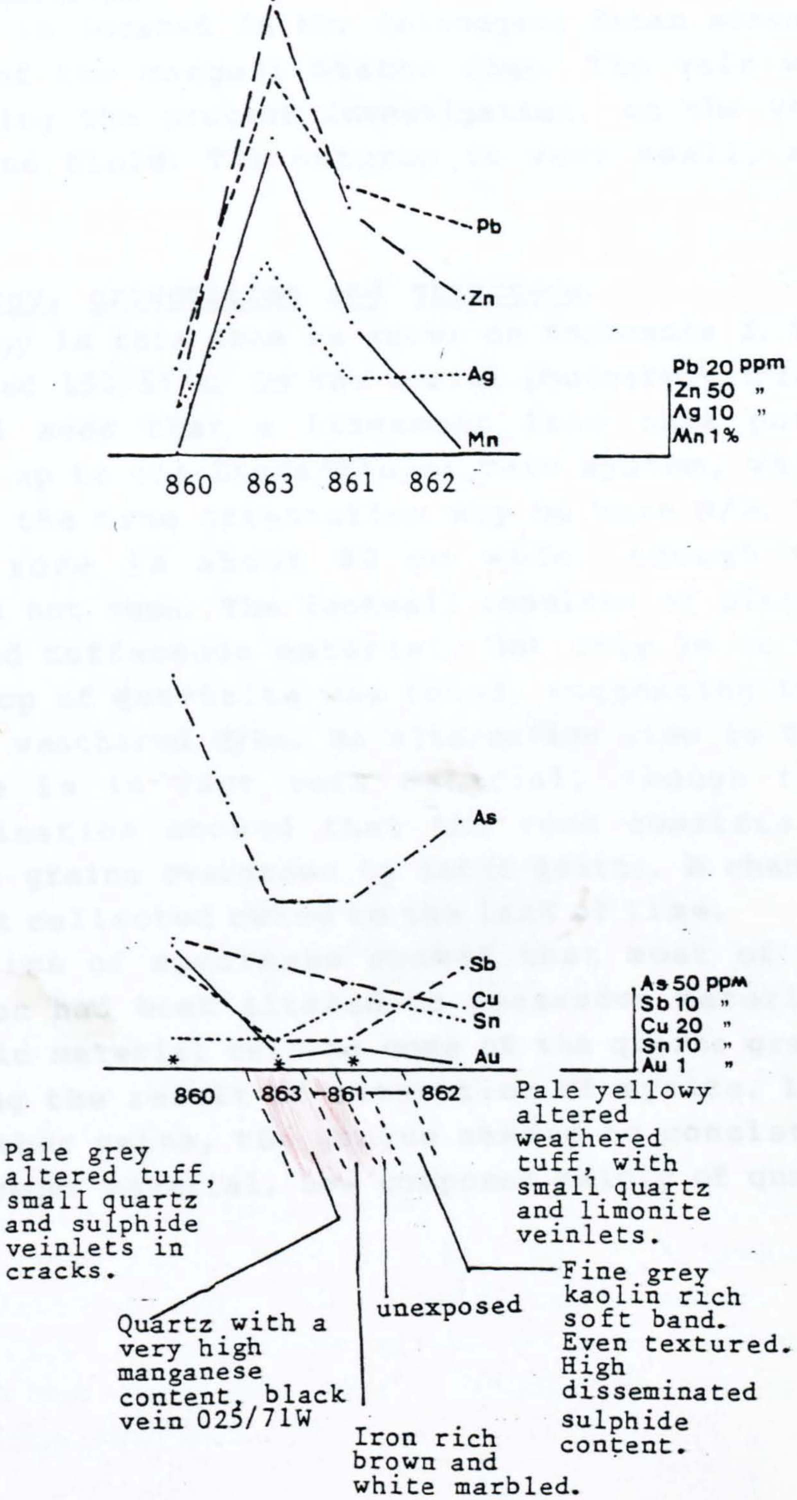
4.14.3 Analytical results

4 channel samples were collected across the width of this vein (Fig. 65). The manganese content is very high, and is the cause of the black colour. The base metal content is fairly low, but tin and antimony are present, and the arsenic content is quite high. Both gold and silver are present in some of the samples, though not in large amounts.

The presence of precious metal, in combination with a high manganese and arsenic content is similar to the element combinations found in the Mangani Vein. Some parts of the Mangani Vein area much more valuable than others, suggesting that though the precious metal content in this outcrop is low, other parts may be more valuable.

Figure 65.

Analytical results and sketch cross section of the Galanggang Black Vein.



Samples	Cu	Pb	Zn	Mn	Ag	Au*	Sb	Sn	As
Ma R860	32	22	38	195	6	0.70	16	4	260
861	20	70	160	1.75%	10	0.15	4	10	125
862	14	60	100	80	10	-0.05	14	6	165
863	26	100	300	4.15%	25	0.05	4	4	110

4.15 Cie Lei Vein

4.15.1 Introduction.

This vein is located in the Galanggang Kanan stream, to the south of the Mangani Graben edge. The vein was discovered during the present investigation, on the very last day in the field. The outcrop is very small, and overgrown.

4.15.2 Geology, orientation and structure.

The geology in this area is shown on Enclosure 2. The vein is oriented 150/69°E. On the aerial photograph (Plate 12) it can be seen that a lineament from this point extends north up to the Linda/Eloise Vein system, which suggests that the true orientation may be more N/S. The mineralised zone is about 80 cm wide, though the hangingwall is not seen. The footwall consists of altered very weathered tuffaceous material, but only 5m to the west an outcrop of quartzite was found, suggesting that this may be a weathered dyke. An alternative view is that the quartzite is in fact vein material, though thin section examination showed that the rock consists of rounded quartz grains overgrown by later quartz. A channel sample was not collected owing to the lack of time.

Examination of specimens showed that most of the mineralisation had been altered to gossanous material, with haematitic material veining some of the quartz grains probably being the result of alteration of pyrite. like many of the other veins, the gangue seemed to consist of altered tuffaceous material, now composed mainly of quartz and kaolin.

4.16 Brani Vein

4.16.1 Introduction

This vein was found outcropping on the north bank of the Rambutan River in 1912. The northern part of the Brani vein was found when the road was built, and was initially thought to be a promising new vein, but only contained a good metal content near the surface. During the present investigation the lowest adit near the river has been investigated, as well as the adit built by the local people 10 metres higher up. A number of other adits were seen, but not investigated.

4.16.2 Tunnels.

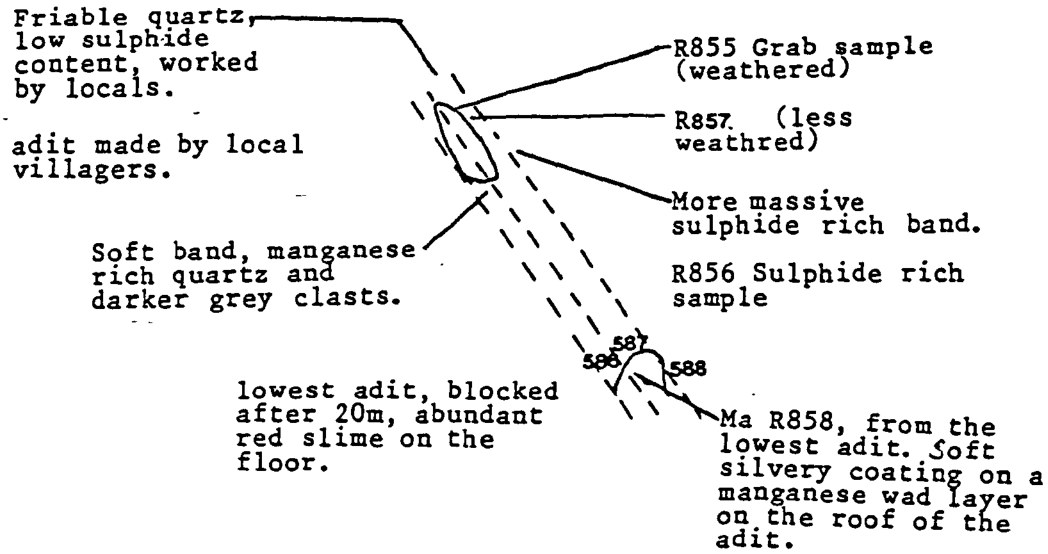
In 1914 (M.M. Aequator annual report) two tunnel levels were built at the northern outcrop point of the Brani Vein, extending for a total length 98m, as well as cross cuts. In the same year the Brani main tunnel (T101) was extended to 200m, and 59m away from the straight line to avoid an area of bad rock. The tunnel along the fault cutting off the southern part of the Mangani Vein was also extended by 235m in 1915, with the hope of eventually encountering either the other part of the Mangani Vein, or the northern part of the Brani Vein, if these were different. It was planned to use the Brani Vein for dewatering the Mangani mine.

At present the tunnel just above river level still exists, though blocked by a roof fall about 15m in. Red sulphide-rich water drains from under the blockage. Local villagers were mining a 50cm thickness near the footwall for about 10m above this tunnel in 1982. The vein seems to have been accessed by about 10 tunnels approximately 25m apart vertically, in a N/S line up the steep valley side. Many of these can still be found, though few appear to continue far into the vein.

4.16.3 Geology and orientation

Brani Conglomerate forms the host rock for the vein, though outcrops of volcanics can be found nearby (Enclosure 2). The vein is oriented 175-015/75-75°E.

Figure 66. Analytical results and geological sketch of the Brani Vein.



Sample	Cu	Pb	Zn	Mn	Ag	Au	Sb	Sn	As ppm
Ma R855	2	18	10	60	13	0.25	16	-4	390
857	30	85	36	38	26	0.15	28	-4	350
858	32	20	100	160	2400	70.0	185	-4	75

4.16.4 Vein size.

A width of 16.5m was seen near the river, though M.M. Aequator mining reports state that further into the vein a screen of conglomerate is present. Still further to the north the two parts of the vein rejoin (8m width).

The vein is cut off by a fault in the south, but De Haan et al. (1933) report that the known length of the Brani Vein north of the river was 400m.

The Bangket Vein may be the southern continuation.

4.16.5 Analytical results

3 grab samples were collected during the present study from a sulphide rich band (Ma R857), and a band nearer to the footwall (Ma R855) (Fig. 66), from the villagers adit about 10m above the bottom tunnel. R858 was a sample of an unknown thin soft grey/green silvery layer on top of a gossanous layer, which appeared to be a secondary deposit on the roof of the bottom tunnel. Most of the material was collected, but Dr J Bowles (personal communication) collected a sample from the same place 6 months later, suggesting that it formed quite quickly. The Ag and Au content of this material was very high. Sb was also concentrated , but manganese was surprisingly low in this material.

Near the river M.M Aequator considered a length of 40m to be workable, 1m of the footwall and 1.5m of the hangingwall. The vein as a whole was considered to contain too many inclusions of host rock to be workable, though the small amounts of workable ore found contain a high Ag:Au ratio, like the Mangani Vein. De Haan mentions that initial samples varied from 60-850g/tonne Ag, and 0.5-18g/tonne Au, and that values decreased steadily northward.

The following samples were collected by P.T. Aneka Tambang (Maas 1979), and show that high gold values are present in some samples.

MN/A/6	2.32ppm Au	123.58 ppm Ag
MN/A/7	0.72	11.78
MN/A/8	0.76	15.54
MN/A/9	0.90	15.10
MN/A/10	10.04	1035.81
MN/A/11	2.40	64.80

Samples from the Brani Vein are generally low in base metals, despite the presence of visible pyrite and base metal veinlets in one band. Ag and Sb are present, but not in large amounts, but As is high.

The presence of secondary Au and Ag suggests that veins at Mangani may well be affected by supergene enrichment, and that this a rapid process, possibly associated with the presence of manganese.

4.16.6 Petrology

3 samples from this vein were examined in thin section. Generally samples were very similar in appearance to material collected from the Rumput Pait Vein, consisting either of fine granular quartz, carbonate and kaolin, or containing the remnants of clasts, possibly derived from the Brani Conglomerate. In most samples the sulphide material had weathered to a haematitic mass, but some samples still contained either scattered pyrite crystals, or cross cutting pyrite and quartz veinlets. Despite the large vein width, and the presence of separate bands, most of the vein seems to have formed as a result of alteration of pre-existing material, rather than as a result of quartz precipitation in a fracture. Some cross cutting veinlets of quartz crystals up to several centimetres in width are present, but appear to be the result of the very last mineralisation phase.

4.17 Bangket Vein

4.17.1 Introduction.

This vein is mentioned only in a report by Truscott in 1911. The name was derived from the Banket deposits in South Africa, as it was initially thought that the auriferous conglomerates adjacent to the vein were similar to those deposits. This vein was not investigated during the present study, though an adit with a considerable depth of red mud was found (marked on enclosure 2).

4.17.2 Available information

The following items of information are probably all that is known about this occurrence.

Stollen (tunnel) 4 was built to investigate the vein. The best values were near the tunnel mouth.

The vein is oriented NW/SE, dipping 75°SE. A well defined quartz reef, 25-30cm wide is present, hosted in Brani Conglomerate and sandstone. The vein is reported to consist of banded and manganiferous quartz along a very good fracture. Assays ranged from 1-5dwt. Much of the conglomerate host rock is also auriferous, but in a very irregular fashion. Generally only the soft rock near the vein surface is auriferous, not the harder rock away from the vein. The width of this alteration zone is not known.

4.18 **Sampil Vein**

4.18.1 Introduction

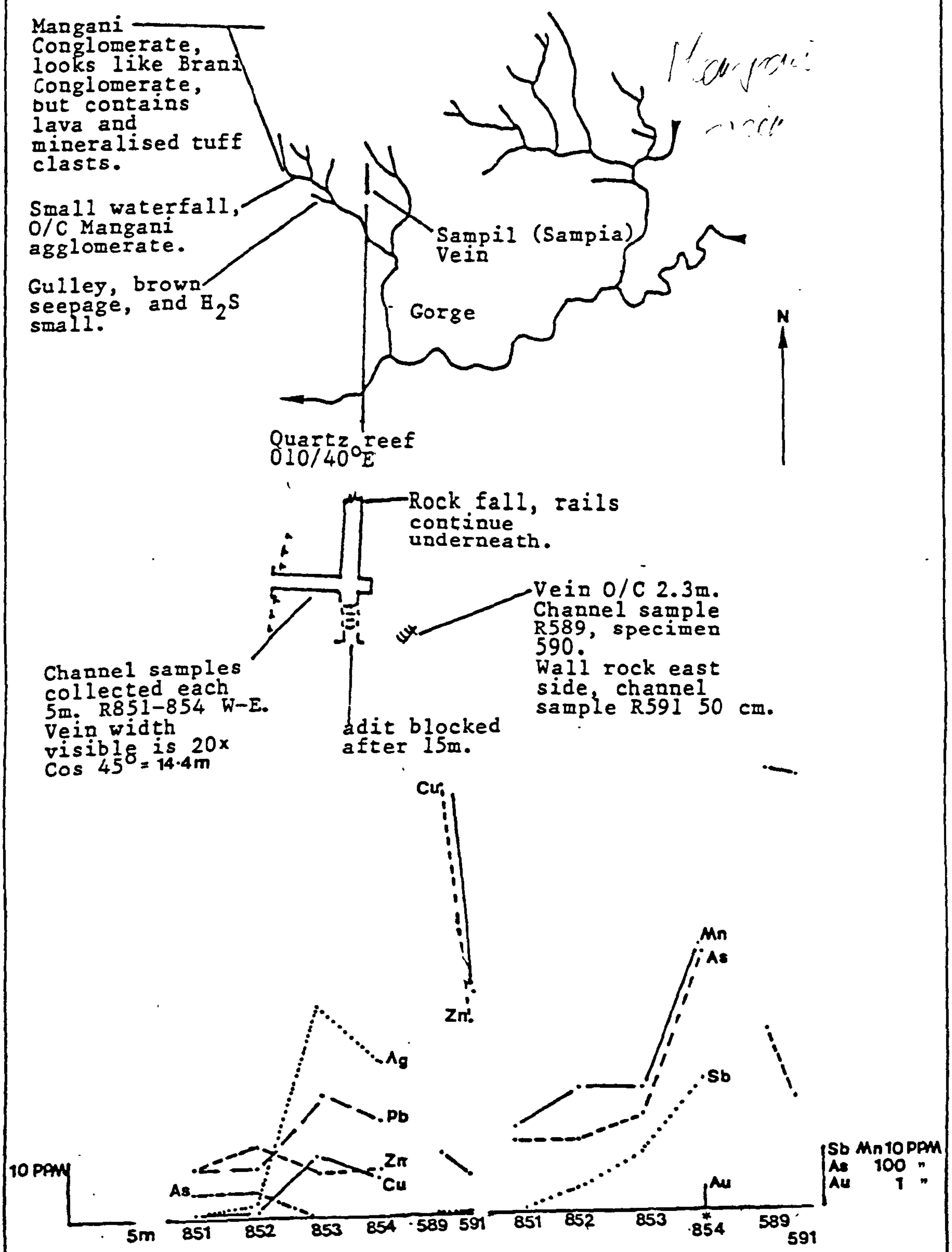
Figure 67 shows the location of the Sampil Vein. This vein was discovered during the life of the Mangani mine, and one of the Rumput Pait mine maps marks an adit leading to this vein. An adit into this vein is still present, but is blocked by a rock fall after 20m. Rails can be seen disappearing under the rock fall, suggesting that this vein and the Rumput Pait Vein are connected. It is possible that some part of this vein was mined by M.M. Aequator, though it is not mentioned in the annual reports, and when Boomgaart (1948) speculated that the Sampil Vein was the southern part of the Rumput Pait Vein, De Haan wrote a reply suggesting that this was not the case.

A southern outcrop of the Sampil Vein marked on the geological map published by De Haan et al. (1933) was not investigated during the present study as it occurs in a gorge, and no means of access could be found.

Local people call this vein the Sampia Vein, and this name has also been found in a number of post-1940 reports.

Figure 67.

Geological sketch map of the area around the Sampil Vein



Analytical results from the Sampil vein

Sample	Cu	Pb	Zn	Mn	Ag	Au	Sb	Sn	As	Ni	Co	Cd	Fe	Bi	Cr
Ma R851	-2	8	8	14	-1	-0.05	-4	4	120						
852	-2	8	12	20	2	-0.05	4	4	115						
853	10	20	8	20	35	-0.05	10	-4	160						
854	6	16	8	44	26	0.40	22	-4	430						
589	10	255	70	175	3				300	1	7	1	4.20	-0.5	1
591	7	37	32	170	2				200	2	4	1	2.32	-0.5	4

4.18.2 Geology

The geology of the area near this vein has not been investigated in detail, as access was difficult. Near the vein most of the outcrop consists of tuffs, as well as a conglomerate (Mangani Conglomerate) similar in appearance to the Brani Conglomerate, as it contains reworked Brani, as well as volcanic components. Further to the south in the Rambutan River all the outcrop consists of Brani conglomerate. The entire area is located within the Brani Horst, the volcanics probably lying on top of the Brani Conglomerate.

4.18.3 Mineralisation

Outcrop of a small part of the quartz reef is located on the hill ridge, where the eastern boundary with altered weathered granular tuff can be seen. The orientation at this point is 040/60^{o}E, while in the adit the orientation appears to be 010/40^{o}E. The total vein width visible in the adit is about 15m, and if the vein outcrop on the hillside is not a hangingwall split, then the total vein width must be more than 25m.

The Sampil Vein is a quartz reef with a very similar appearance to the Rumput Pait Vein as seen in the adits to the south of the B. Kulit Manis ridge. It consists of very hard banded clear and milky quartz, with locally the appearance of agate. Grey coloured patches are caused by the presence of fine disseminated sulphides. The host rock on either side looks like very altered tuff, or may be a tuffisite dyke similar to those near the northern part of the Rambutan Vein. The rock is pale grey with large white feldspar crystals, and fine disseminated sulphides.

4.18.4 Analytical results

4 samples were collected from the quartz reef from within the adit, as well as 2 samples from the vein exposed on the hillside. The analytical results and locations of these samples are shown in Figure 67. The base metal content is low, though the vein on the hillside contains 255 ppm Cu. Cu, Pb, and Ag appear to be correlated, though the Zn content appears to be unconnected with the quantities of other elements present. Mn, As and Sb are correlated, and the sample containing

the largest amount also contains some Au. The footwall of the vein exposed in the adit has a lower element content than the 10m near the hangingwall. The graphs of the element contents suggest that a more sulphide rich part of the vein may be present between the two outcrops investigated.

The following samples were collected by P.T. Aneka Tambang (Maas 1979). The exact location of these samples is not known, but the Au content is much higher than in the samples collected during this investigation.

MN/A/21	3.34 ppm Au	42.64ppm Ag
MN/A/22	1.78	66.70
MN/A/23	0.74	58.50

4.19 Silver Vein

4.19.1 Introduction

The Silver Vein is located in the Rambutan River, a few hundred metres from the Rambutan Vein. This vein is mentioned in M.M Aequator report for 1922, as well as De Haan et al. (1933), and Boomgaart (1948) This vein was worked by Marsman mining corporation. Details about the mining problems are recorded in Dermout (1941).

4.19.2 Adits

Entrances to adits into this vein are still present on both sides of the Rambutan River. The remains of a watertight door on the south side of the river suggests that lower levels may be present. An adit about 25m above the river level was also seen on the south side of the river. On the ridge between the Rambutan and Galanggang River an adit just below the surface may also have been built to investigate this vein. Further to the north, on this same ridge, the remains of a mine shaft are present, reputed to have been destroyed by the Japanese.

4.19.3 Geology

The host rock is Brani Conglomerate. Details of the geology and structure of this area are shown in Enclosure 3.

To the south of the river a hard quartz reef oriented 160/65^{o}E is covered with red seepage. This occurs to the west of a gulley, suggesting that a softer kaolinised zone has been eroded, or removed during the Marsman mining operation.

On the hillside to the south of the river an adit was also found, but not investigated in detail, as it contained numerous bats with their young. To the north of the river the vein consists of a 1m wide siliceous zone, with a wide zone of altered kaolinised Brani Conglomerate to the west, while to the east alteration is minimal.

Boomgaart (1948) reports that both this vein and the Rambutan Vein are associated with rhyolite (dacite) dykes. These were not observed in the field, though the gulley to the east of the vein on the south side of the river may have contained such a dyke. The rhyolite is decribed as being highly altered, silicified, pyritised and kaolinised, which suggests that these dykes may in fact be tuffisite dykes. The vein is reported to be hosted in the dyke, with the Brani Conglomerate locally acting as wallrock, when the vein lies between the footwall of the dyke, and conglomerate. There is a sharp contact between the ore and the dyke, and between the dyke and the Brani Conglomerate. The dykes have many splits of all sizes, and a number of independent dykes are also described. This information suggests that though the vein may have formed partly by alteration of the hostrock, the alteration is limited to a single fracture. An alternative explanation is that post-ore dykes are present.

Mapping (Enclosure 3) has shown that in addition to the main mineralised zone, a number of thin kaolinised siliceous bands are present nearby.

In the Galanggang River a number of vein outcrops were found, which are probably the northern extension of the Rambutan and Silver Vein. The Peter Vein (described in the next section) on Figure 5 and Enclosure 3 is most likely to be related to the Silver Vein.

4.19.4 Analytical results

Analytical results for the channel sample of the vein at the northern side of the river, and of the wall rock to the west of the vein are shown on Figure 68.

M.M. Aequator considered that the vein consisted only of a few lumps of good ore in a poorer vein. Generally the vein was richer south of the river than to the north. The following values indicate why the vein was called the Silver Vein.

Si 8	3.5g/tonne Au	501g/tonne Ag
Si 11	1.5	2803
Si 14	2.1	5438

Boomgaart (1948) reports that assays of the dykes associated with the Rambutan and Silver Veins show at most traces of gold, and 30g/tonne silver. In some places the conglomerate is reported to contain much pyrite, but generally does not show visible contact phenomena. Even where it borders the vein directly the Brani Conglomerate does not contain any gold.

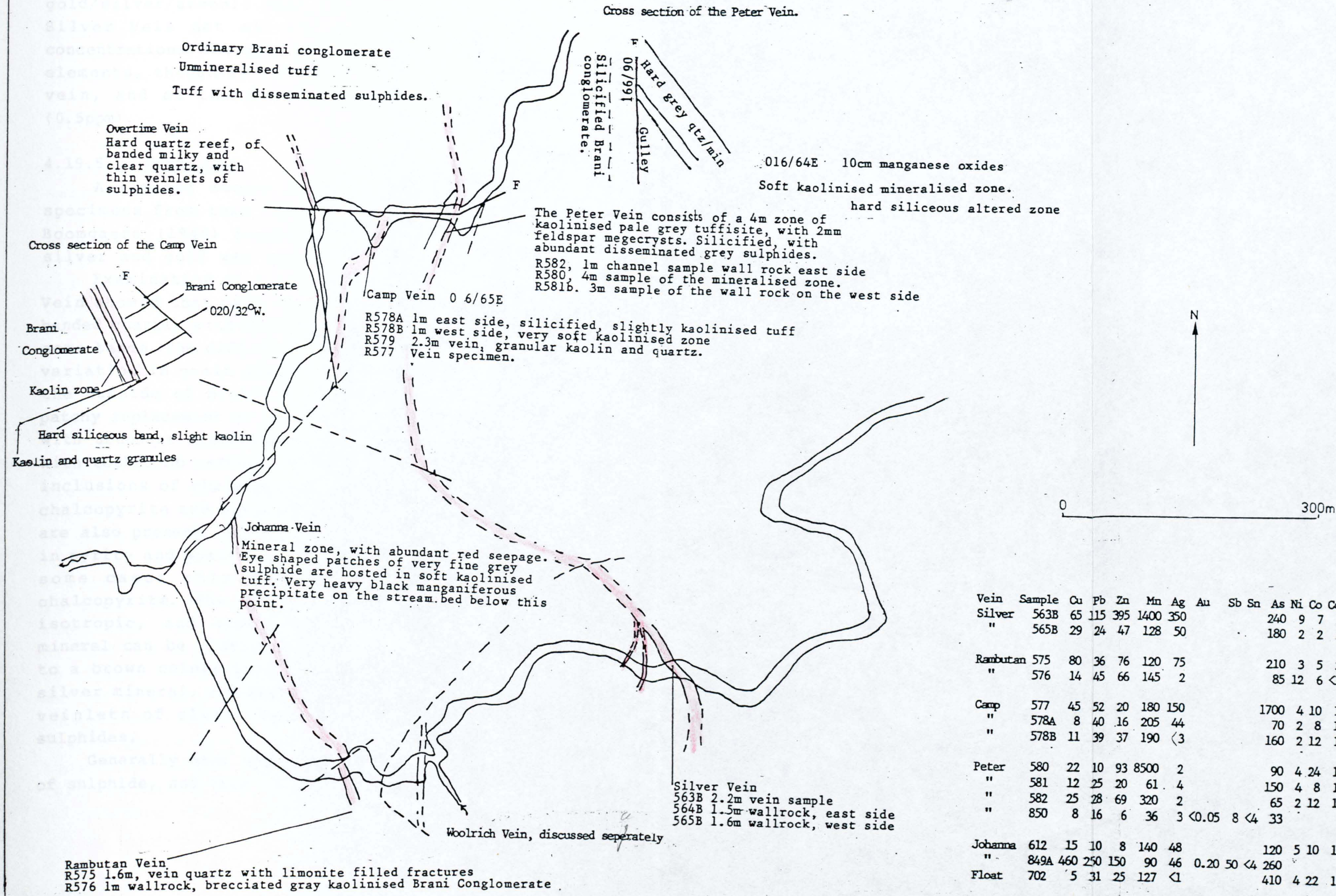
One sample was collected by P.T. Aneka Tambang (Maas 1979), and though containing some precious metal, indicates that not all samples contain such a high Ag content. MA/A/17 1.02g/tonne Au 53.66g/tonne Ag

CSR Ltd collected the following samples from the Silver Vein, but the exact location is not known.

No	Au	Ag	Cu	Pb	Zn	As	Bi	Mn	Mo ppm
A99661	0.10	72	33	47	63	20	0.5	54	<1
	0.09	69.6							
62	0.56	80	76	114	35	260	<0.5	168	1
	0.35	85.3		North adit					
64	0.06	13.5	19	3	20	220	<0.5	91	1
	0.08	18.7							
65	0.09	8.8	12	6	7	11	<0.5	48	1
	0.06	8.03		Vein stockwork					

Gold and silver are present in all samples, though in small amounts. The base metal content is low, and Mo and

Figure 68. Analytical results, location of samples and geological notes on mineralisation in the Rambutan-Silver Vein area.



Vein	Sample	Cu	Pb	Zn	Mn	Ag	Au	Sb	Sn	As	Ni	Co	Cd	Fe%	Bi	Cr ppm
Silver	563B	65	115	395	1400	350				240	9	7	3	7.8	<0.5	18
"	565B	29	24	47	128	50				180	2	2	1	4.23	0.5	3
Rambutan	575	80	36	76	120	75				210	3	5	2	8.4	<0.5	6
"	576	14	45	66	145	2				85	12	6	<1	2.91	<0.5	3
Camp	577	45	52	20	180	150				1700	4	10	1	5.0	<0.5	5
"	578A	8	40	16	205	44				70	2	8	1	3.38	<0.5	1
"	578B	11	39	37	190	<3				160	2	12	1	7.8	<0.5	4
Peter	580	22	10	93	8500	2				90	4	24	1	5.5	<0.5	1
"	581	12	25	20	61	4				150	4	8	1	3.69	<0.5	4
"	582	25	28	69	320	2				65	2	12	1	2.86	<0.5	3
"	850	8	16	6	36	3	<0.05	8	<4	33						
Johanna	612	15	10	8	140	48				120	5	10	1	7.3	<0.5	2
"	849A	460	250	150	90	46	0.20	50	<4	260						
Float	702	5	31	25	127	<1				410	4	22	1	3.21	<0.5	6

Bi are almost absent. The manganese content is also relatively low, though some specimens seen contained quite abundant Mn oxides. This vein could be described as a gold/silver/arsenic vein. Though the vein is named the Silver Vein not all the samples show high silver concentrations. The wall rock contains lower levels of all elements, though Bi is below the detection limit in the vein, and at the detection limit in the wall rock (0.5ppm).

4.19.5 Petrology

A limited amount of previous microscope work on specimens from this vein appears to have been done, as Boomgaart (1948) reports that megascopically visible silver and gold was never found.

Examination of 4 thin sections from the the Silver Vein showed that part of the vein consists of colloform banded quartz, with disseminated sulphides concentrated in some bands. The different bands can be recognised by the variation in grain size. Some of the bands occur around the outside of highly altered silicified clasts, with patchy replacement of the clast material by calcite. Bands with abundant disseminated sulphides consist of veinlets with cockscomb texture. Some of the pyrite grains contain inclusions of chalcopyrite, and disseminated grains of chalcopyrite and sphalerite with "chalcopyrite disease" are also present. An unknown mineral occurs as inclusions in pyrite and spalerite, and scattered in the quartz. In some cases this mineral is partly replaced by chalcopyrite. The mineral is silvery/grey in colour, isotropic, and superficially similar to galena. The mineral can be distinguished from galena as it tarnishes to a brown colour in a few days. This mineral may be a silver mineral, and should be investigated further. Late veinlets of clear cockscomb quartz cut some of the sulphides.

Generally most specimens contain only a small amount of sulphide, and this is fine grained and disseminated.

4.20 Peter Vein

4.20.1 Introduction

This vein is located in the lower part of the Galanggang River, and is the probable continuation of the Silver Vein. No mention of this occurence is present in any of the literature.

4.20.2 Geology and mineralisation

Enclosure 3 is a detailed geological map of the Rambutan-Silver Vein area, and shows the geological setting of this vein. Figure 68 shows the location of samples collected for analysis from this area, and also some annotated sketches of the vein outcrop. This vein lies just to the south of the edge of the Mangani Graben, and appears to be partly hosted in tuff, though Brani Conglomerate outcrops only 20m upstream. The tuffaceous rock was so completely altered that identification of the lithology was difficult, but the presence of fine grained clasts, as well as large feldspar megacrysts suggests that this may be one of the feldspar porphyry, or tuffisite dykes described previously.

The vein consists of a 1.4m hard grey mineralised quartz band, with a 10cm black clay layer at the footwall. Two thin sections from this vein were examined, and showed that the vein material was similar in appearance to many of the highly altered rocks already described. Sulphide material has mostly been removed by weathering, but the remains of disseminated pyrite grains can still be seen. To the west of the black kaolin band is a soft pale kaolinised band. This entire sequence is cut by a steeply dipping fault, beyond which highly silicified Brani Conglomerate occurs. This grades over a distance of a few metres into more normal conglomerate. The tuffaceous host rock at the hangingwall is not particularly sulphide rich. The northward continuation of the vein was not exposed, though the pale colour of the soil suggested that this vein is not cut off by the fault which cuts of the Camp Vein further west.

4.20.3 Analytical results

Figure 68 shows the sample locations and analytical results. Ma R850 is a channel sample across the whole zone. The base metal content of the host rock and the quartz band is fairly low, though the zinc content of the vein is slightly higher than that found in most rocks (93 ppm). The hangingwall tuffaceous rocks also contain slightly higher zinc and manganese (69 and 350 ppm respectively). The manganese content of the vein is significantly higher than in the wall rock (8500 ppm). Arsenic levels in all specimens are quite high, the highest value occurring in the footwall (150 ppm). Bismuth is below the detection limit. The high iron content in the vein probably reflects the high pyrite content. Silver is present in all samples, but only in small amounts (2-4 ppm).

4.21 Rambutan Vein

4.21.1 Introduction

The vein is mentioned in Aequator mining reports of 1922 and 1923. M.M. Aequator did not do further work on this vein after it was decided that the good values just above the river were the effect of the watertable. Later however this vein was worked by the Marsman Mining Corporation, some of the details being reported by Boomgaart (1948). Much of the literature published about Mangani deals with the Rambutan and Silver Veins in the same section, and the geology and mineralisation of the two veins are quite similar.

4.21.2 Tunnels

Adits just above river level were built north and south of the river, and connected by a bridge. The Rambutan south tunnel was extended for a total of 130m in 1923. On the south side of the river three higher adits were also built, as well as a short tunnel between cross-cut III level I, and cross-cut II, level II, with a cross cut halfway (Boomgaart, 1948).

The bridge has now disappeared, but in 1982 the two adit entrances were still present, though the northern side had a deep deposit of red siliceous ooze. In addition the entrances to two higher levels could still be found on the south side of the river. A shaft was also sunk north of the Rambutan River, but is now blocked.

M.M. Aequator maps show the Egert tunnel near the A. Galanggang, which was presumably used to investigate the northern extension of this vein. A small tunnel was found during the present investigation, but this stopped after a very short distance, though it was not clear if this was the end of the tunnel, or a roof fall.

4.21.3 Vein width and orientation

Outcrops exposed in the Rambutan and Galanggang Rivers do not exceed 1.2m in width, though Boomgaart (1948) reports that the width varies between 1m and 7m, averaging 2.5-3m. At the river the orientation is 010/70°E. The dip is reported to be unaffected by the orientation of the bedding in the host rock.

4.21.4 Geology

The vein is reported by Boomgaart (1948) to be hosted in a rhyolite (dacite) dyke, and in the Brani conglomerate. The dyke was not evident in the exposure in the Rambutan River, but may have been obscured by the supports for the bridge that used to cross the river. The dyke is described as being extremely altered, and may in fact be a feldspar porphyry or tuffisite dyke. The description of the geology around the Silver Vein also applies to this vein, the two being only a short distance apart.

Enclosure 3 shows the details of the geology and structure near the Rambutan and Silver Veins. A number of outcrops of vein material probably consisting of the northern extension of the Rambutan and Silver Veins were found during the present investigation in the A. Galanggang. The structure of the area is complex, so that at four places vein material can be seen along the river, but probably these are only the faulted parts of two veins.

4.21.5 Structure

Enclosure 3 shows a number of faults which are interpreted as having cut the Rambutan Vein into a number of short sections in the northern part.

In the mine two types of faults are described by Boomgaart (1948).

1/ Longitudinal faults striking 015-020°. These faults are considered to be syngenetic, as they are reported to have locally acted as barriers to the mineralising fluids in a similar way to that described by De Haan et al. (1933) in the Mangani Vein. Such faults would be formed as dextral synthetic faults related to tensional forces in the Mangani Graben, as described in Chapter 2.

2/ Cross faults striking 110/120. The cross faults are younger than the ore deposition as they are reported to be unmineralised, though ore is dragged along the faults. The vein on the two sides of the cross faults is also of the same width and character. Faults with such an orientation are parallel to the Mangani Graben edges, and should be normal faults, but they appear to have acted as dextral faults (Fig. 15). This may however be an apparent displacement, caused by normal movement.

4.21.6 Mineralisation and analytical results.

Analytical results from samples collected during the present survey are shown in Figure 68. The silver content in the vein is quite appreciable (75 ppm), with only 2 ppm in the wall rock. The base metal content is moderate, with a slight enrichment of zinc and lead in the wall rock. The arsenic contents are quite high, with 210 ppm in the vein and 85 ppm in the wall rock.

De Haan et al. (1933) report that analytical results from trenches along the vein surface were considered to be quite encouraging. Results were better in the south of the river than the north. Boomgaart (1948) reported 13 analytical results, from different cross cuts, which indicate an average of width of 2.5m, 2.6 ppm Au and 171 ppm Ag.

Boomgaart (1948) reports that in the Rambutan Vein north of the river ore has a peculiar rose pink colour as a result of the weathering of manganese carbonate. This contrasts with the statement by De Haan et al. (1933) that the manganese content is low, and is probably another example of the inhomogeneity of veins in the Mangani area.

CSR Ltd collected the following sample from the same location as Ma R575. The analytical result is very similar, suggesting that there have been no problems of contamination or analytical errors.

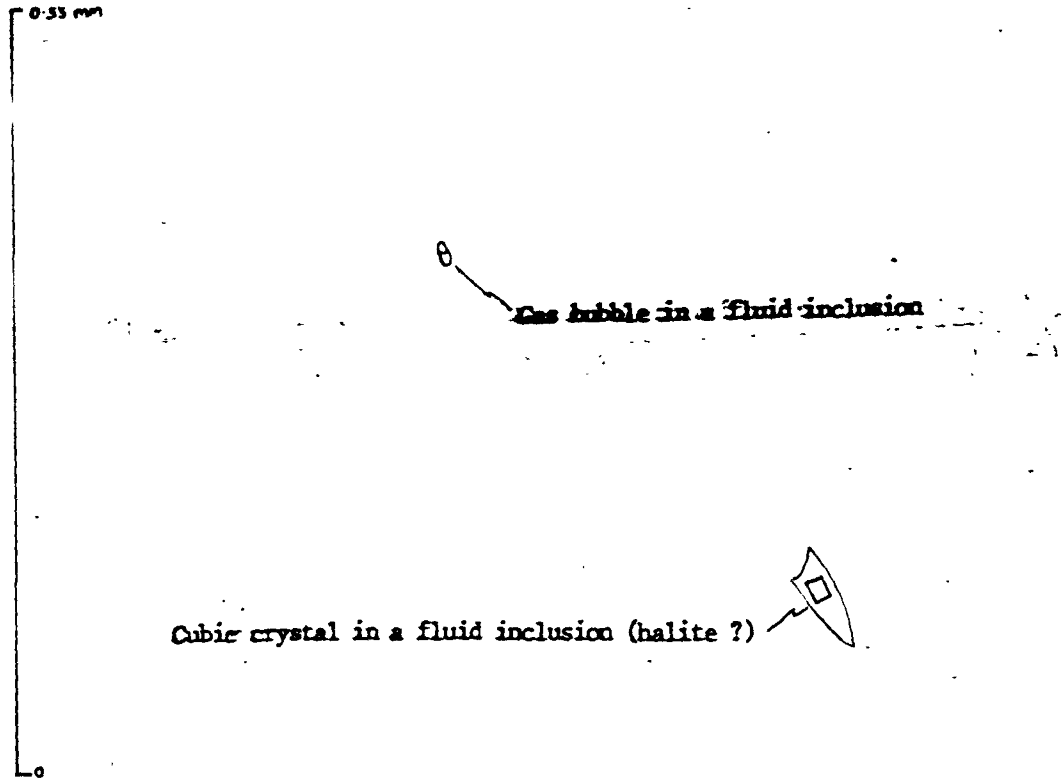
No	Au	Ag	Cu	Pb	Zn	As	Bi	Mn	Mo ppm
A99663	2.9	124	70	99	26	300	<0.5	87	<1

4.21.7 Petrology

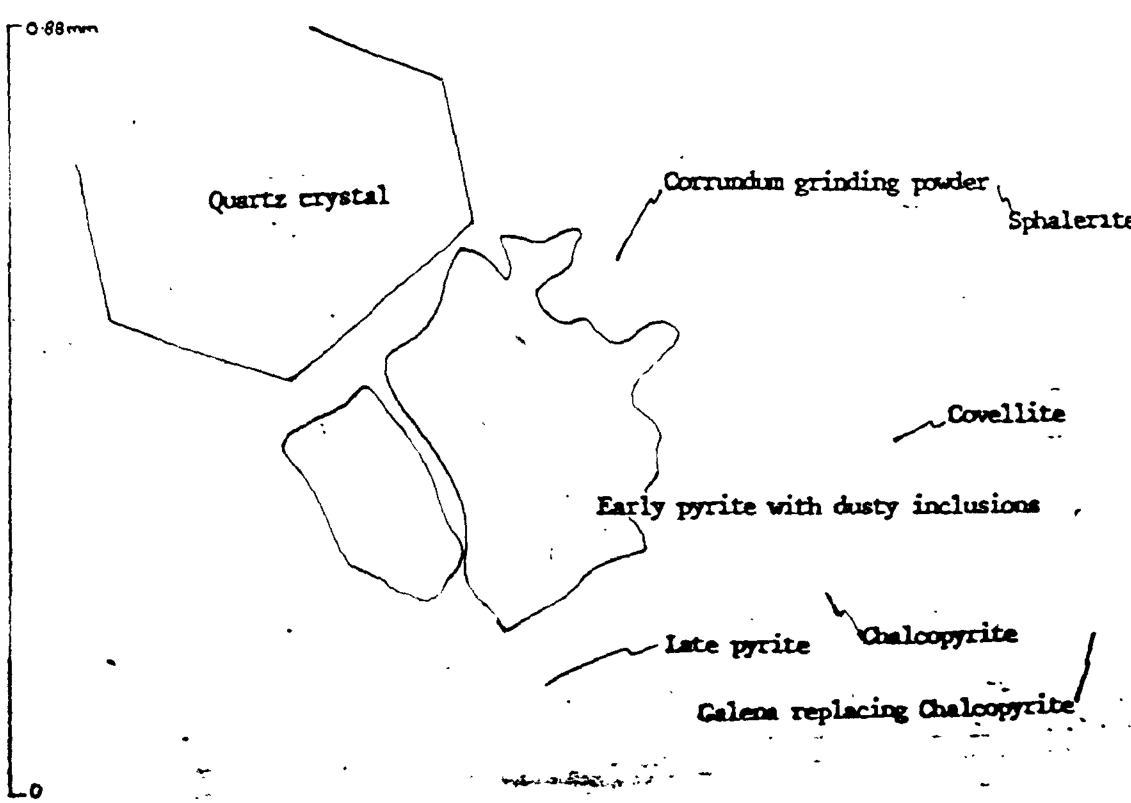
Three samples of vein material were examined in thin section. The vein material in some places consists of large interlocking quartz crystals, with very occasionally remnants of earlier finer grained material still visible. These may have been clasts of host rock, or this vein may have formed like many others at Mangani by total alteration of the pre-existing rock. This last interpretation may be more valid, as some samples consist of a very fine grained aggregate of carbonate and clay minerals overgrown by patches of quartz. In some cases a parallel alignment of the long axes of grains is present, and quartz grains show strain extinction, suggesting that the veins have been deformed. Such samples contain abundant fine grained Fe and Mn oxides impregnating the rock. Disseminated pyrite crystals are present, and very fine grained pyrite occurs in rectangular shaped patches, suggesting that this has replaced feldspar grains. Plate 22a shows the very high abundance of fluid inclusions in a sample collected from the north side of the Rambutan River. The irregular shape of some of the inclusions suggests that they have been affected by remobilisation. Many inclusions contain bubbles, and some contain a daughter crystal, the cubic shape suggesting the presence of halite.

Early dusty brown colloform pyrite is present, often with overgrowths of later pyrite, both types being partially altered to haematite as a result of weathering. Chalcopyrite with very small rounded sphalerite inclusions sometimes replaces pyrite. Very rarely, small tetrahedrite particles are present. A very small amount of galena occurs in the Rambutan Vein, which may either be occurring

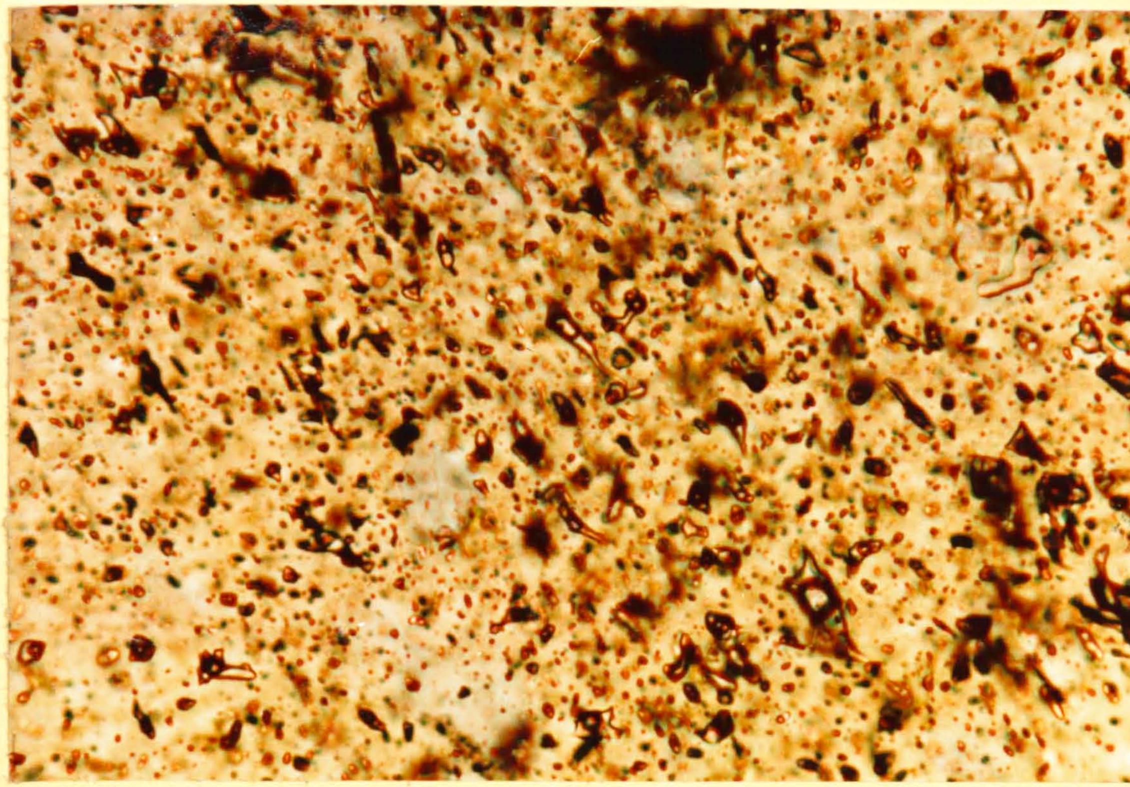
Plate 22



a. Thin section of gangue from the Rambutan Vein, showing the very abundant fluid inclusions.



b. Photomicrograph of a polished section from the Rambutan Vein (R70A), showing minerals and textures.



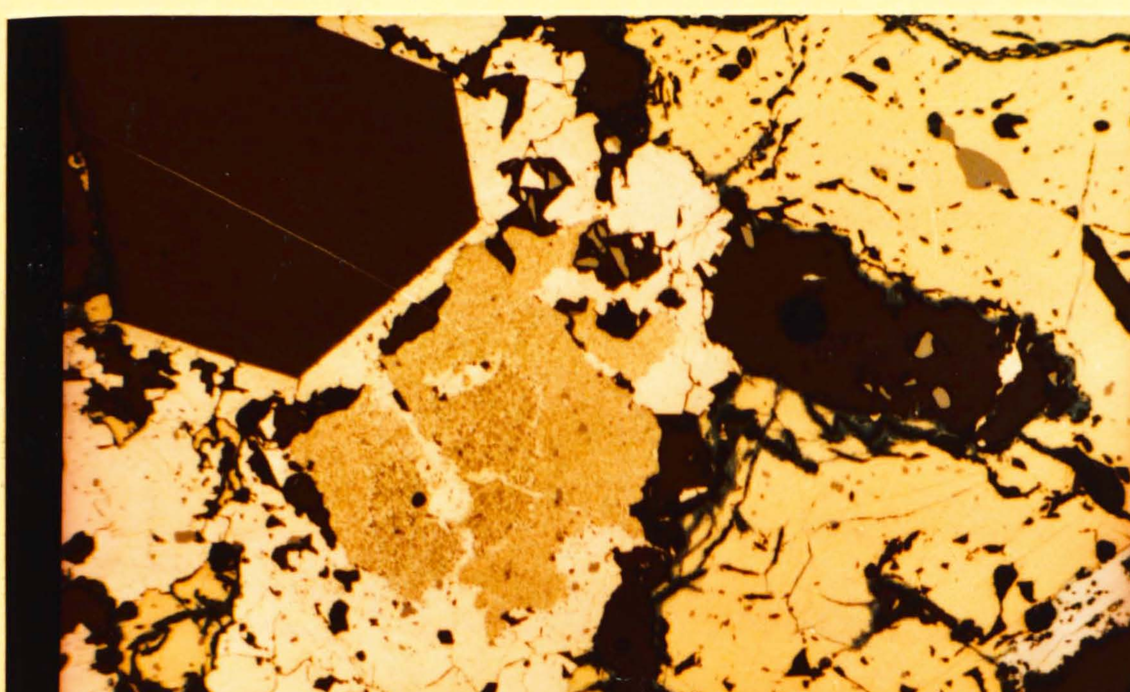
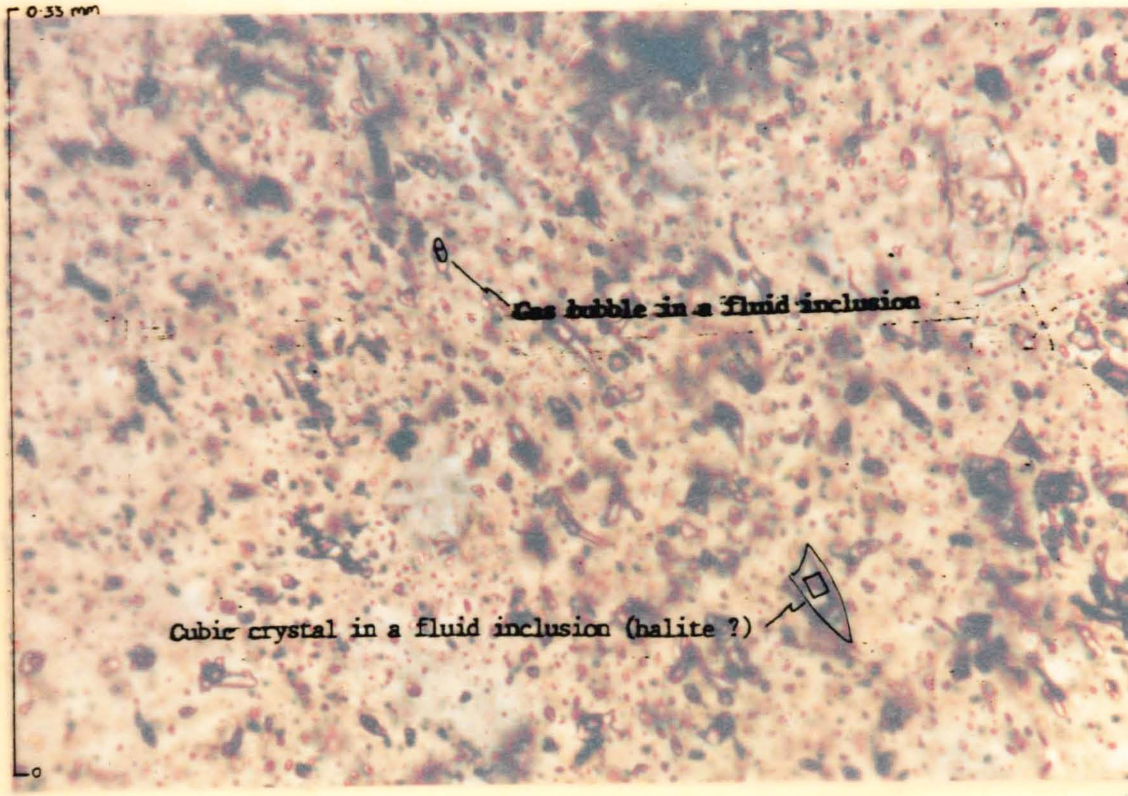
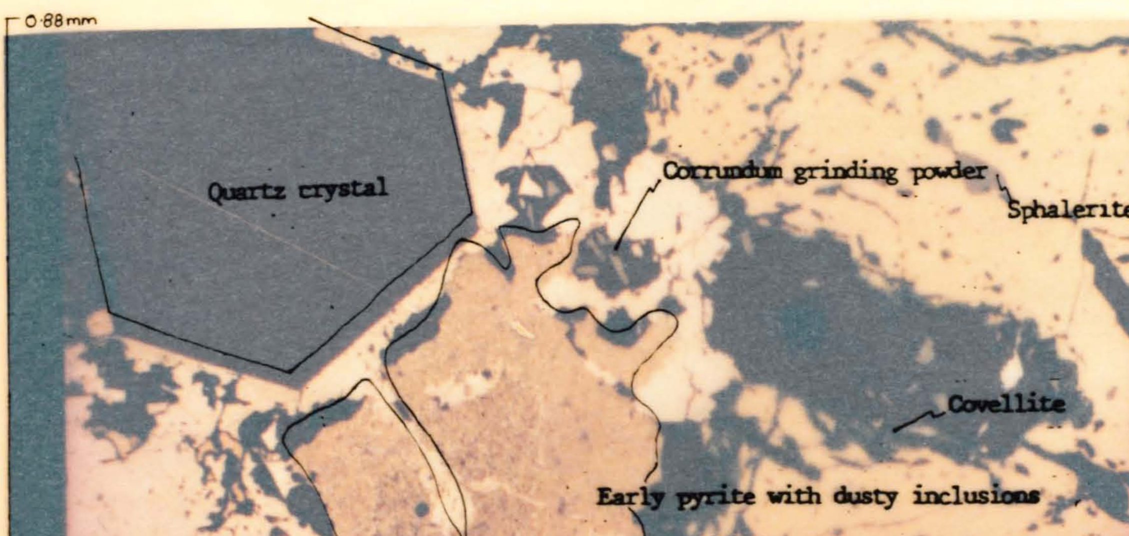


Plate 22



a. Thin section of gangue from the Rambutan Vein, showing the very abundant fluid inclusions.



b. Photomicrograph of a polished section from the Rambutan Vein (R70A), showing minerals and textures.

as inclusions in chalcopyrite, or is replacing the chalcopyrite. The chalcopyrite is often altered to covellite at grain boundaries. Most of these features are illustrated in Plate 22b.

4.22 Johanna, Overtime and Camp Veins

4.22.1 Introduction

Figure 68 shows three vein outcrops in the Galanggang River, which may be part of the northern extension of the Rambutan Vein. The northward extension of The Rambutan and Silver Veins is not discussed in any of the literature, and Boomgaart (personal communication) could only remember having seen one or two of the different outcrops.

4.22.2 Geology, structure and mineralisation

Enclosure 3 shows details of the geology of the area around these veins, and additional information is shown on Figure 68. These veins may be part of a single vein, separated by faulting. Generally outcrop in this area consists of Brani Conglomerate, though some tuffaceous material occurs. The tuffaceous material mostly consists of intrusive tuffisite, though it is possible that small fault slices of bedded tuff are present, as this area is very close to the southern edge of the Mangani Graben.

The Johanna Vein consists of a kaolinised zone, with oval eye-shaped patches of very fine sulphide. Red seepage dripped down the whole outcrop, making sampling difficult. Only this kaolinised zone is exposed, though there may well be an associated quartz reef. The vein does not continue to the north, as relatively unaltered Brani Conglomerate outcrops on the north side of the stream. A few metres to the east an outcrop of very kaolinised Brani Conglomerate occurs.

The Overtime Vein consists of a very hard quartz reef, with thin veinlets of sulphide. The host rock at the footwall was Brani Conglomerate, with only slight signs of alteration. The host rock to the east is not exposed, a narrow gulley running parallel to the vein possibly being caused by erosion of a kaolin zone. M.M. Aequator mine maps show an adit at this point called the Egert Tunnel.

An adit was found, which only seemed to penetrate the vein for a short distance, but other adits may possibly be present higher up the slope. The vein can be followed northward for at least 20m. The southward continuation of the vein was not exposed. Possibly the vein was present in the stream bed, though Brani Conglomerate to the east was bounded by a polished fault surface, indicating that there is a fault with almost the same orientation as the vein.

The Camp Vein consists of a band of highly altered, kaolinised, silicified tuffaceous material, with very abundant finely disseminated sulphides. A band near the footwall consists of granular kaolin and quartz, suggesting that this material has been brecciated. The next band to the west consists mainly of kaolin. The total zone is 2.3m thick. The host rock consists of Brani Conglomerate, with a bleached altered appearance, trending 032/20^{o}W. A very low, small adit is present.

4.22.3 Analytical results

The locations of samples collected from this area, as well as the analytical results, are shown in Figure 68.

The channel sample (612) of the Johanna Vein contains only low values of base metals, and the manganese content is also very low, despite the presence of a very thick black precipitate downstream from this point. The arsenic content is quite high (120 ppm), and silver also occurs in moderate amounts (48 ppm). The iron content is quite high, matching the high pyrite content. A grab sample of the sulphide-rich part of this vein contains much higher base metal contents, with copper being the most abundant (460 ppm). Manganese is again very low (46 ppm). Gold and silver are present in moderate amounts (0.2 ppm and 46 ppm), while arsenic and antimony contents are quite high (260 and 50 ppm). Tin is below the detection limit.

A sample of pyritised altered feldspar porphyry float collected just upstream of this point (702) contains very similar element contents to the Johanna Vein, with the conspicuous absence of silver. The high arsenic content suggests that most of the visible silvery grey disseminated sulphide is arsenopyrite.

A channel sample of the Overtime Vein was collected, but was lost durng transport of samples.

Three samples from the Camp Vein were analysed. Generally the Camp Vein contains fairly low amounts of base metals, and the manganese content is also low. The concentrations in the wall rock are comparable, or lower. Bismuth is below the detection limit. Silver is present in considerable amounts in the vein (150 ppm), and in moderate amounts in the hangingwall (44 ppm), and a few ppm of silver are present in the footwall. Arsenic is very high in the vein (1700 ppm), and also quite abundant in the footwall (160 ppm). The arsenic content of the hanging wall was also higher than that in many veins (90 ppm). Like arsenic, iron was more abundant in the footwall than the hangingwall, and in this case was also more abundant than in the vein. This may possibly be the result of the original iron content of the Brani Conglomerate, the matrix often being haematitic. Like all the other veins in this area, bismuth is absent. A grab sample (850) from this vein was also analysed, and shows a very similar picture. Gold and tin are below the detection limit, and a few ppm (8) of antimony are present.

Four samples from the Peter Vein were analysed. The Peter Vein is similar to the other veins in containing a low base metal content, and a few ppm of silver, but the manganese content is high (8500 ppm). Arsenic is again slightly more abundant in the footwall (150 ppm), than in the vein (90 ppm). In this case the iron content is highest in the vein (5.5 %), as a result of the greater pyrite content. Bismuth is again absent.

4.22.4 Petrology

One or two samples from each of these veins were examined in thin section. Most of these veins were very similar in appearance to many of the other highly altered kaolinised silicified rocks already described. Sulphide veinlets were not seen, though disseminated pyrite and arsenopyrite were sometimes recognisable despite the high degree of weathering of these quite porous rocks.

The Johanna Vein contains primary quartz grains, which are not the result of silicification, in a fine grained aggregate of carbonate and clay minerals. Rectangular outlines suggested that very large feldspar grains had been present originally. Very small pyrrhotite inclusions are present in pyrite.

The Overtime Vein consists of material totally different in appearance from any other vein investigated at Mangani. The vein consists partly of beautifully banded agate-like quartz. Some bands are coarsely crystalline, or cockscomb, while other parts consist of very fine grained colloform banding. Fibrous bands are also present, including bands with radial 1mm fibres growing out from an impurity at the boundary with the previous band. If sulphides are present they are extremely fine grained.

4.23 **Woolrich Vein**

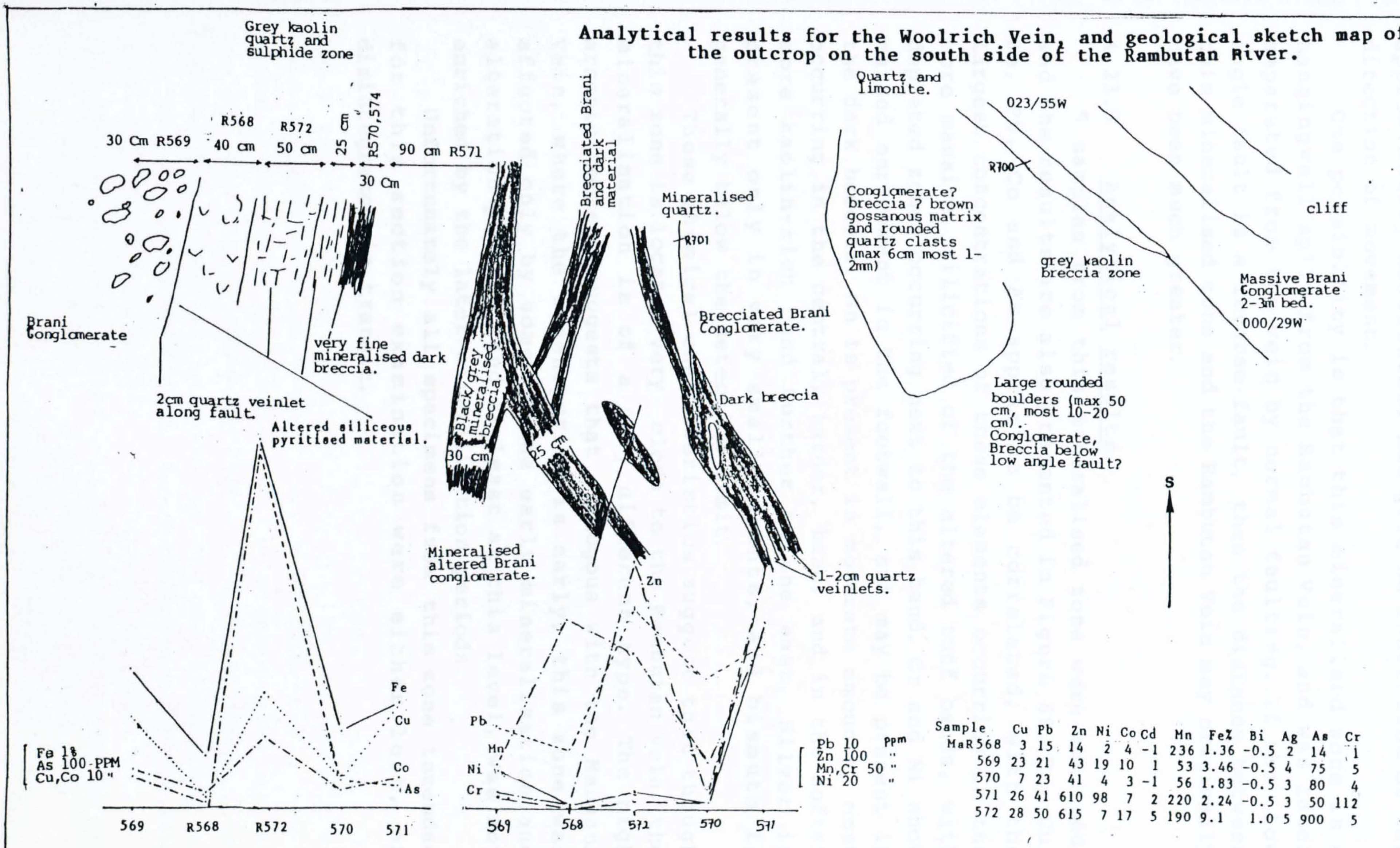
4.23.1 Introduction.

This mineralised zone was discovered during the present investigation by Dr. Paul Woolrich. The mineralisation outcrops on the south bank of the Rambutan River, between the Rambutan and Silver Veins.

4.23.2 Geology.

The geological map of this area (Enclosure 3) shows the geological setting of the mineralisation. The lithology in this area consists of Brani Conglomerate locally intruded by intermediate to acid fine grained dykes. The area has been affected by a number of faults, though the displacement on these faults is unknown.

Figure 69 shows a sketch of the outcrop, where it can be seen that the mineralisation occurs below a low angle fault. Below the fault the rock appears to consist of a mega-breccia, with blocks up to several metres in diameter. Most blocks consist of altered mineralised Brani Conglomerate, but some gossanous material is also present. Further to the east, veins of dark breccia (igneous ?) containing abundant fine arsenopyrite and pyrite intrude into altered Brani Conglomerate, and are cut by later quartz veinlets. Still further to the east, bands of siliceous tuffaceous material containing abundant grey fine disseminated sulphides, together with a band of dark mineralised breccia, are cut radically by a vertical fault. Beyond the fault the Brani Conglomerate is only slightly altered. Striations on the fault are



Sample	Cu	Pb	Zn	Ni	Co	Cd	Mn	Fe%	Bi	Ag	As	Cr
MaR568	3	15	14	2	4	-1	236	1.36	-0.5	2	14	1
569	23	21	43	19	10	1	53	3.46	-0.5	4	75	5
570	7	23	41	4	3	-1	56	1.83	-0.5	3	80	4
571	26	41	610	98	7	2	220	2.24	-0.5	3	50	112
572	28	50	615	7	17	5	190	9.1	1.0	5	900	5

Figure 69. Analytical results and geological sketch of the Woolrich Vein.

approximately horizontal, but give no indication of the direction of movement.

One possibility is that this mineralised zone is a hangingwall split from the Rambutan Vein, and was later separated from the vein by normal faulting. If the low angle fault is a reverse fault, then the distance between this mineralised zone and the Rambutan Vein may originally have been much greater.

4.23.3 Analytical results.

5 samples from this mineralised zone were analysed, and the results are also presented in Figure 69. Fe, Cu, Zn, Pb, Co and As appear to be correlated, with the largest concentrations of these elements occurring in the more massive, silicified of the altered tuff bands, with depleted zones occurring next to this band. Cr and Ni show marked enrichment in the footwall, and may be present in the dark breccia. Mn is present in moderate amounts, most occurring in the central, harder, band, and in the softer more kaolin-rich band further to the east. Silver is present only in very small amounts, and bismuth is generally below the detection limit.

These chemical characteristics suggest that though this zone is located very close to the Rambutan Vein, the mineralisation is of a very different type. The high arsenic content suggests that analogous with the Mangani Vein, where the arsenopyrite is early, this zone was affected only by some of the early mineralisation and alteration periods, and at least at this level, was not enriched by the later mineralisation periods.

Unfortunately all specimens from this zone intended for thin section examination were either lost, or disintegrated in transit.

4.24 Tumbuk Vein

This is a quartz vein described by De Haan et al. (1933) as being hosted in the Brani Conglomerate, in the A. Pagadis to the south and west of the Brani Vein. The vein is reported to contain no ore of value.

4.25 Serassah Vein

4.25.1 Introduction

This vein is marked on a map published in De Haan et al. (1933), but is not mentioned in the text. "Serassah" means waterfall in the Mingangkabau language. The vein is located in the headwaters of the S. Botung (Fig. 2), in the middle of a large waterfall, at the junction of two streams.

4.25.2 Mineralisation

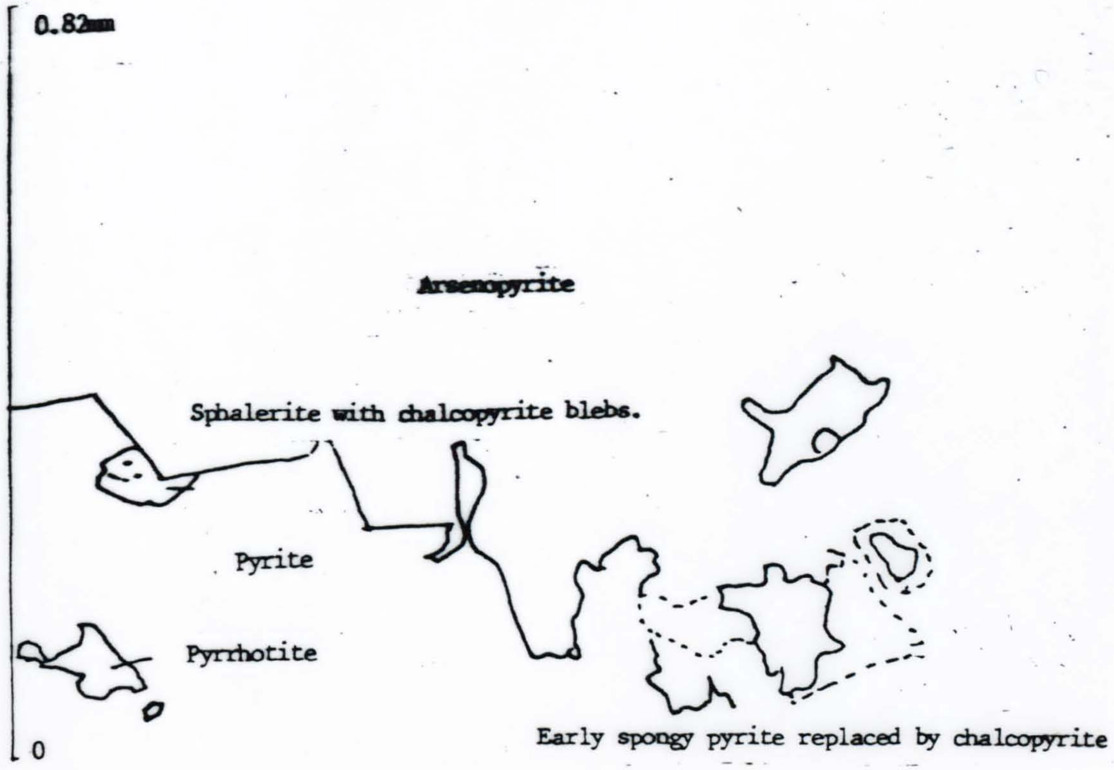
Two samples were collected from a thin sulphide-rich band at the top of the western waterfall. Analytical results are given as ppm, except where indicated.

	Cu	Pb	Zn	Mn	Ag	Au	Sb	Sn	As
Ma R823	5800	6.3%	5.4%	840	138	0.15	115	530	17%

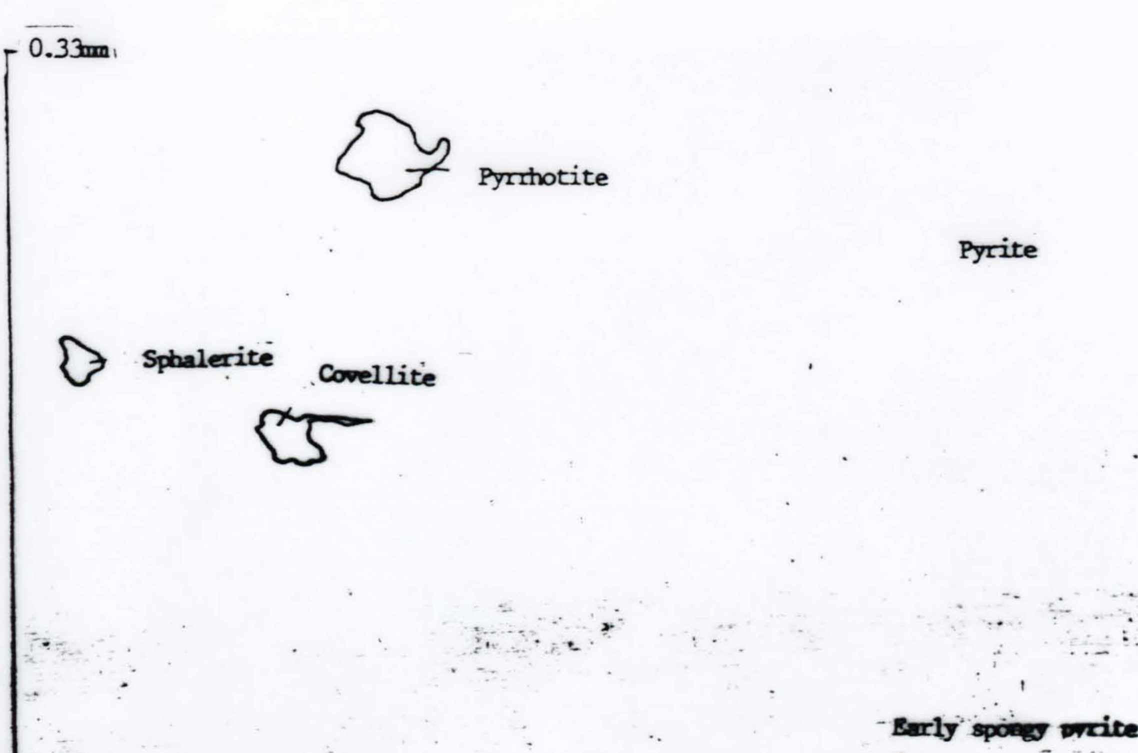
These results suggest that much of the pyrite visible in the hand specimen is in fact arsenopyrite. The presence of silver suggests that this occurrence may be worth invesigating further, but this was not possible during the present period of investigation due to the location of the outcrop in the middle of the waterfall, and its long distance from the camp.

Examination of polished sections showed that abundant early arsenopyrite crystals with pyrrhotite inclusions, occurred veined and surrounded by pyrite. In some cases the arsenopyrite also seems to contain inclusions of early granular pyrite. Sphalerite in the arsenopyrite may be early, but could possibly be a later replacement of pyrrhotite. Sphalerite both occurs as inclusions in pyrite, and replaces pyrite. Sphalerite commonly contains chalcopyrite inclusions, sometimes as "chalcopyrite disease". Larger chalcopyrite grains also occur interstitial to the pyrite, sometimes replacing the

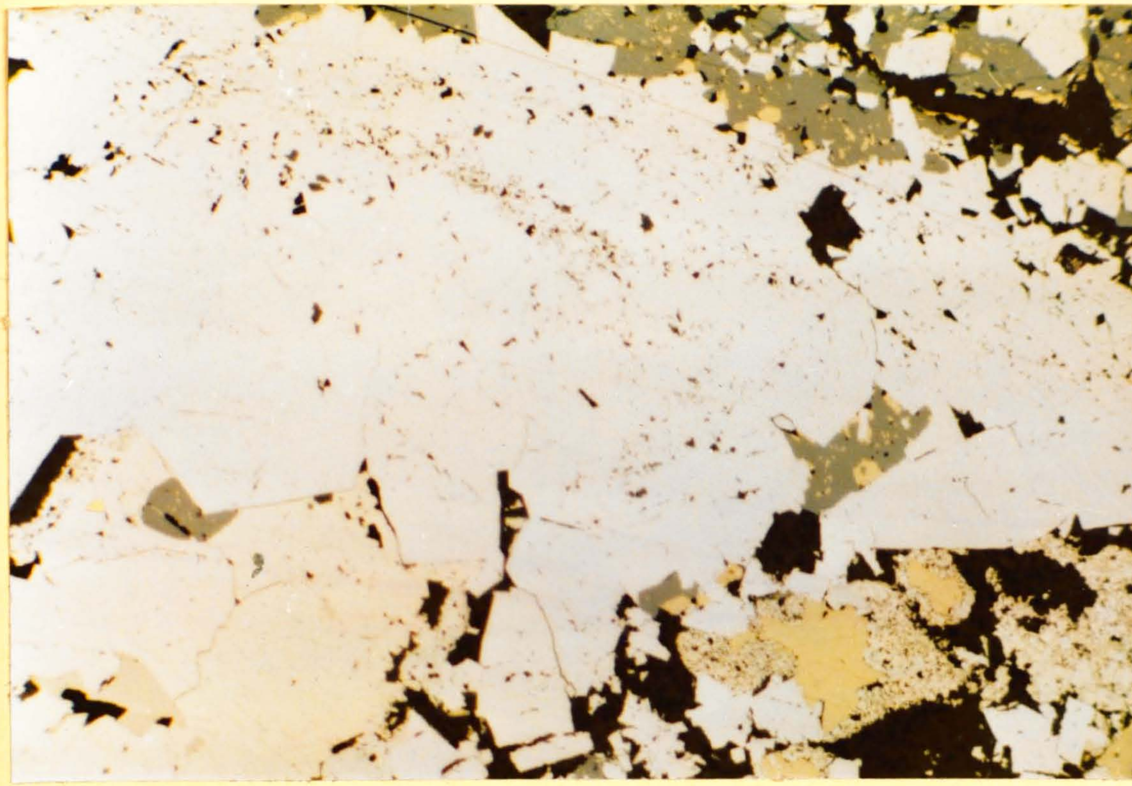
Plate 23



a. Photomicrograph of a polished section from the Serassah Vein (R864), showing minerals and textures.



b. Photomicrograph of a polished section from the Serassah Vein (R864), showing the presence of covellite.



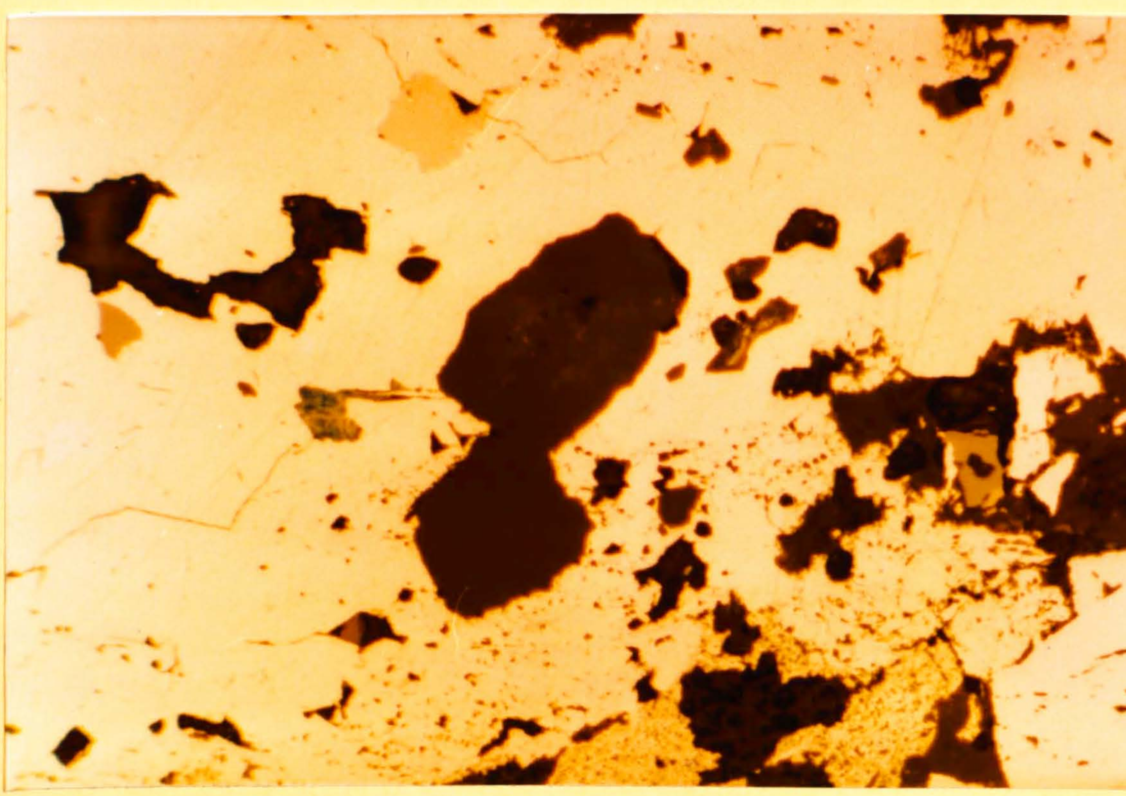
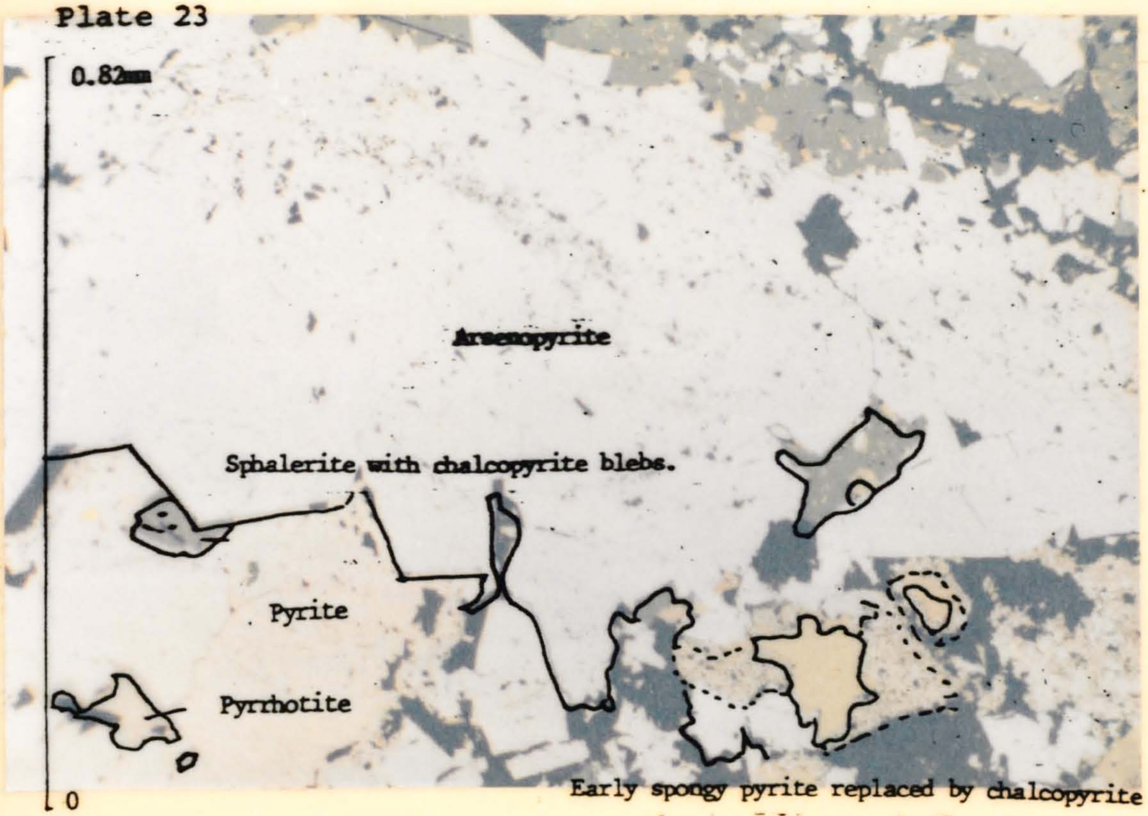
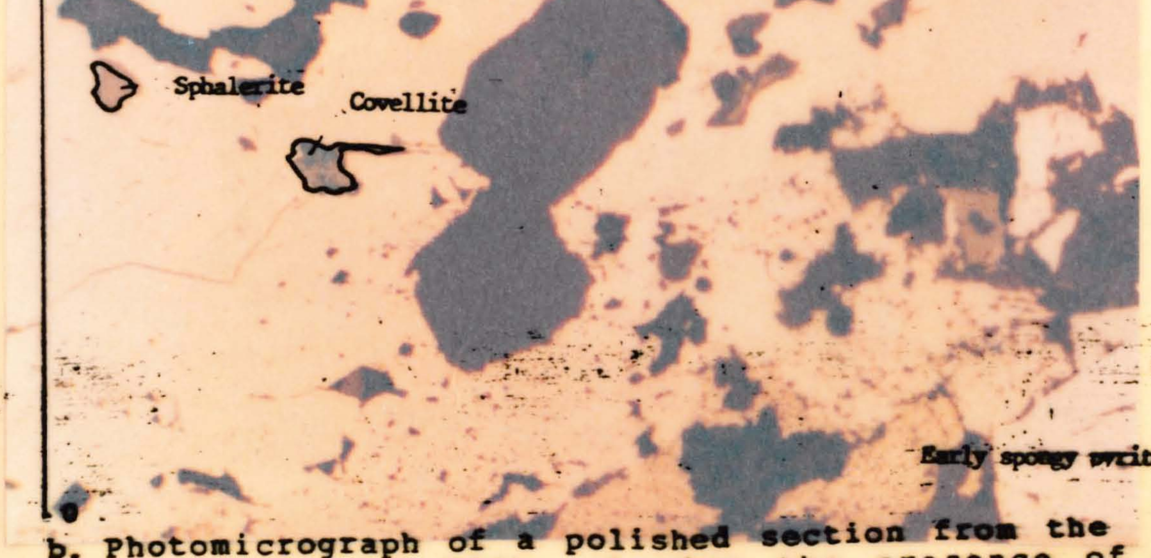


Plate 23



a. Photomicrograph of a polished section from the Serassah Vein (R864), showing minerals and textures.



b. Photomicrograph of a polished section from the Serassah Vein (R864), showing the presence of covellite.

earlier granular pyrite (Plate 23a). A small amount of galena occurs in chalcopyrite and pyrite, and may be early, or may be replacing these minerals. Small covellite grains occur in pyrite as granular aggregates, easily identifiable by the blue-grey reflection pleochroism (Plate 24b). These may possibly be alteration products of chalcopyrite.

The general order of deposition of minerals is:- pyrrhotite, arsenopyrite, pyrite, sphalerite-chalcopyrite, galena, with late pyrite occurring as cross cutting veinlets. Pyrrhotite is not particularly abundant, and the ore petrology is similar to the Mangani Vein, which together with the abundance of Sb suggests that this occurrence may be related to more valuable mineralisation.

4.26 Rambutan Atas Vein

4.26.1 Introduction.

This vein was discovered during the present investigation. The Rambutan Atas Vein is located below the gorge in the Rambutan River, near the northern margin of the Mangani Graben.

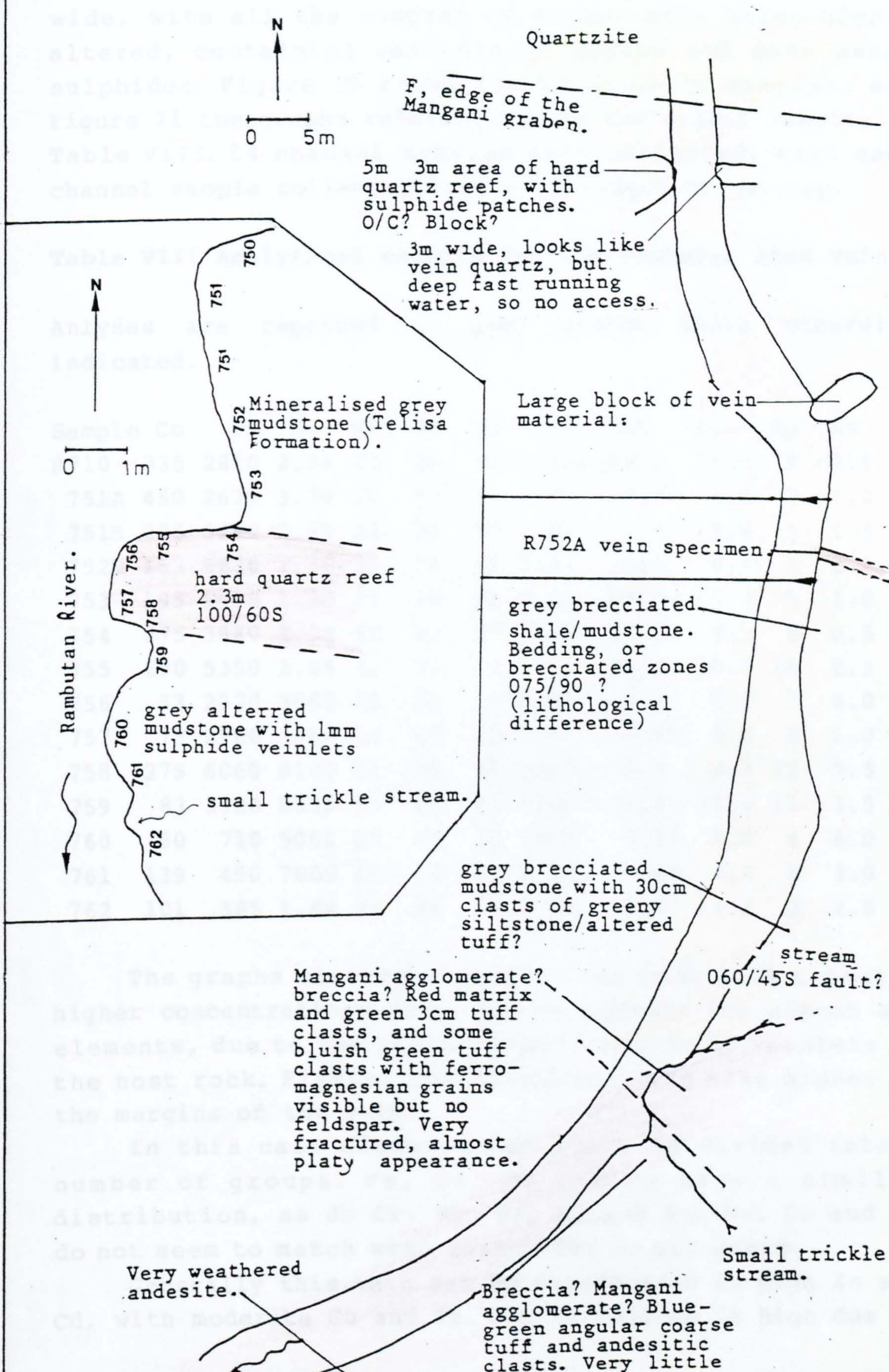
4.26.2 Geology.

The vein is hosted in grey mudstones and shales of the Telisa Formation, though this lithology only occurs here as a thin strip (Figs. 10 and 70), between Sihapas Formation quartzites and conglomerates to the north, and Mangani Formation volcanics to the south. This vein is located very near to the northern edge of the Mangani Graben.

4.26.3 Structure.

The vein is oriented 100/60°SE, and therefore may not be part of the Rambutan Tinggi Vein, despite the fact that if that vein continues to the south, it should outcrop in this area (the orientation of the Rambutan Tinggi Vein is difficult to determine, but appears to be 050/70°W). The orientation of this vein is similar to the edge of the Mangani Graben, and this vein may well be hosted in a fault parallel to the main movement surface.

Figure 70. Geological sketch map of the Rambutan Atas Vein area.



4.26.4 Mineralisation.

The vein itself consists of a hard quartz reef, 2.3m wide, with all the outcrop on either side being highly altered, containing veinlets of pyrite and base metal sulphides. Figure 70 shows the location of samples, and Figure 71 the graphs relating to the analytical results in Table VIII. 14 channel samples were collected, with each channel sample collected from a 1m length of outcrop.

Table VIII Analytical results for the Rambutan Atas Vein

Anlyses are reported as ppm, except where otherwise indicated.

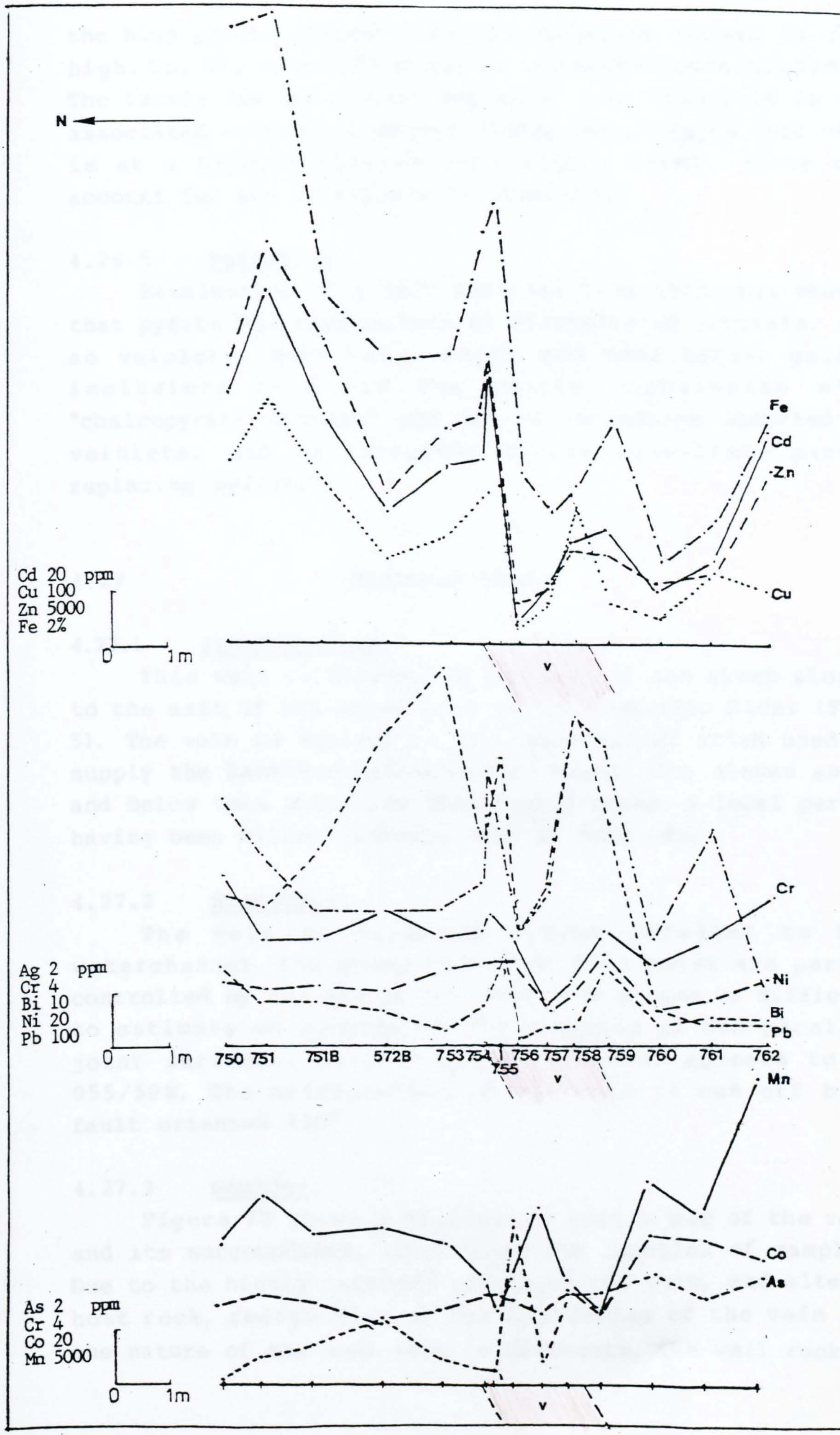
Sample	Cu	Pb	Zn	Ni	Co	Cd	Mn	Fe%	Bi	Ag	As	Cr
R710	335	2810	2.5%	23	28	91	1.29%	22.4	15.0	9	<0.5	13
751A	450	2670	3.7%	21	34	130	1.73	22.7	8.0	7	1.0	8
751B	295	3690	2.8%	23	30	83	1.40	12.9	8.0	5	1.5	8
752B	153	5830	1.36	21	24	49	1.47	10.4	6.0	5	2.5	10
753	195	6950	1.96	29	29	64	1.32	10.6	3.0	5	1.0	8
754	275	3840	2.08	32	32	67	9500	15.1	8.0	6	0.5	9
755	290	5350	2.4%	32	33	97	6300	16.2	15.0	10	0.5	10
756	33	2070	3600	32	31	8	9700	6.2	0.5	3	6.0	8
757	73	2960	4980	14	27	22	1.67	4.85	4.0	6	1.0	3
758	275	6060	8100	21	35	38	9500	5.8	4.0	12	3.5	5
759	83	3920	8350	35	28	41	7300	8.6	15.0	11	3.5	9
760	50	710	5050	15	55	19	186%	3.03	4.0	4	4.0	6
761	139	450	7000	19	54	32	1.53	4.63	5.0	8	3.0	8
762	101	385	1.64	27	48	79	2.8%	8.5	4.0	2	4.0	11

The graphs clearly show that the host rock contains higher concentrations than the vein proper for almost all elements, due to the higher concentration of veinlets in the host rock. Element concentrations are also higher in the margins of the vein.

In this case elements can again be divided into a number of groups. Fe, Cd, Zn and Cu have a similar distribution, as do Cr, Ni, Bi, Pb and Ag. Mn, Co and As do not seem to match with each other or any group.

Generally this vein can be categorised as high Zn and Cd, with moderate Cu and Pb. The Fe content is high due to

Figure 71. Analytical results for the Rambutan Atas Vein.



the high pyrite content, and the manganese content is also high. Co, Ni, Cr and Bi occur in moderate concentrations. The fairly low Bi content suggests that this vein is not associated with the Rambutan Tinggi Vein, though that vein is at a topographically much higher level, which may account for the difference in chemistry.

4.26.5 Petrology

Examination of 3 thin sections from this area showed that pyrite was common both as disseminated crystals, and as veinlets. Both very small, and some larger galena inclusions occur in the pyrite. Sphalerite with "chalcopyrite disease" and pyrite inclusions occurred in veinlets, and as irregular grains, sometimes partly replacing pyrite.

4.27 **Rambutan Tinggi**

4.27.1 Introduction.

This vein is located on the side of the steep slopes to the east of the upper part of the Rambutan River (Fig. 5). The vein is exposed in the waterchannel which used to supply the Rambutan hydroelectric plant. The slopes above and below this point are dangerously steep, a local person having been killed recently when he fell off.

4.27.2 Structure.

The vein is oriented almost parallel to the waterchannel. The steep slopes at this point are partly controlled by the dip of the vein. The strike is difficult to estimate on account of the presence of sub-parallel joint surfaces. Overall the orientation appears to be 055/50W. The northern end of the vein is cut off by a fault oriented 130°.

4.27.3 Geology.

Figure 72 shows a geological sketch map of the vein and its surroundings, as well as the location of samples. Due to the highly oxidised nature of the vein, and altered host rock, recognition of the boundaries of the vein and the nature of the host rock is difficult. The wall rock to

Figure 72. Geological notes on the Rambutan Tinggi Vein.

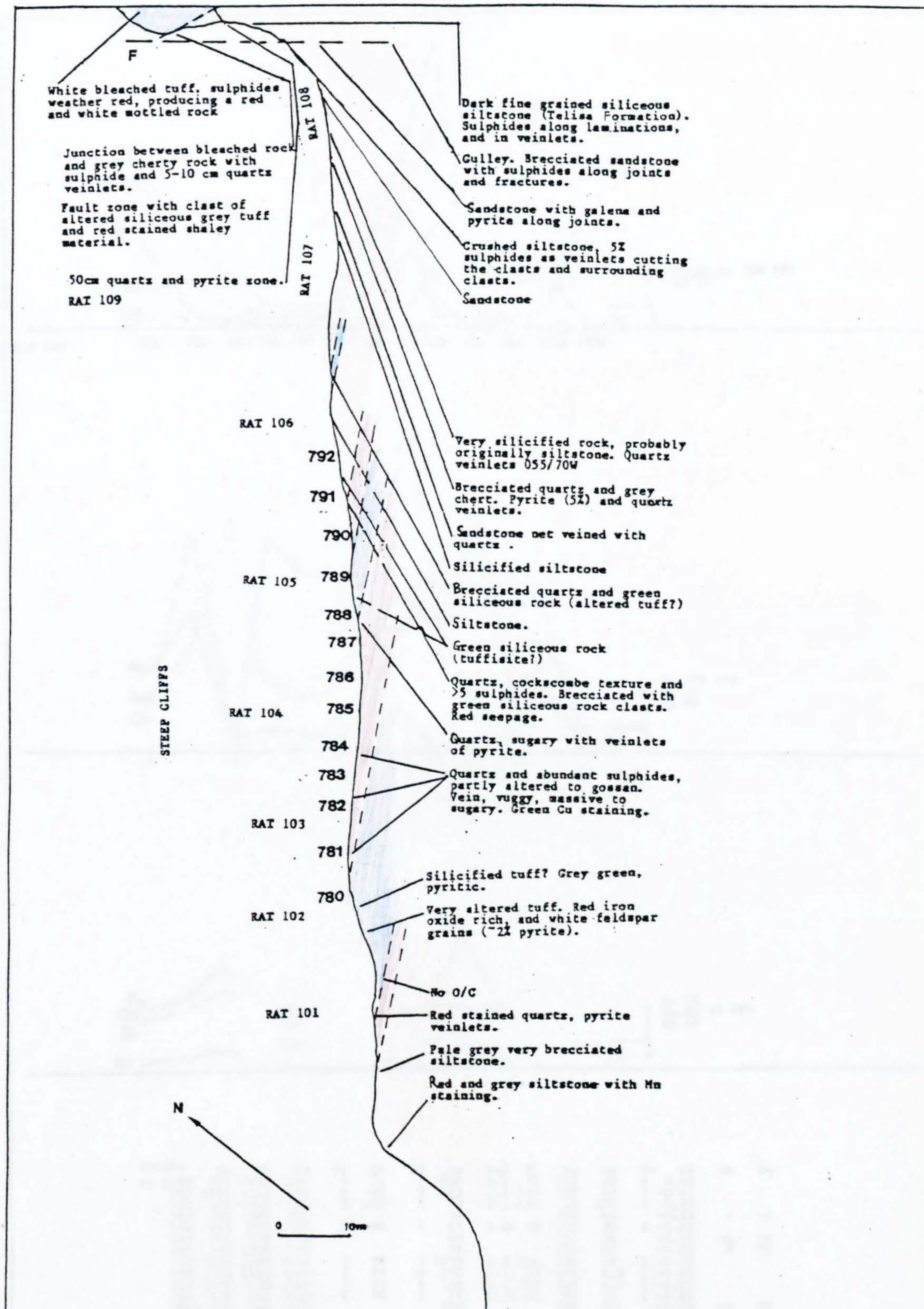
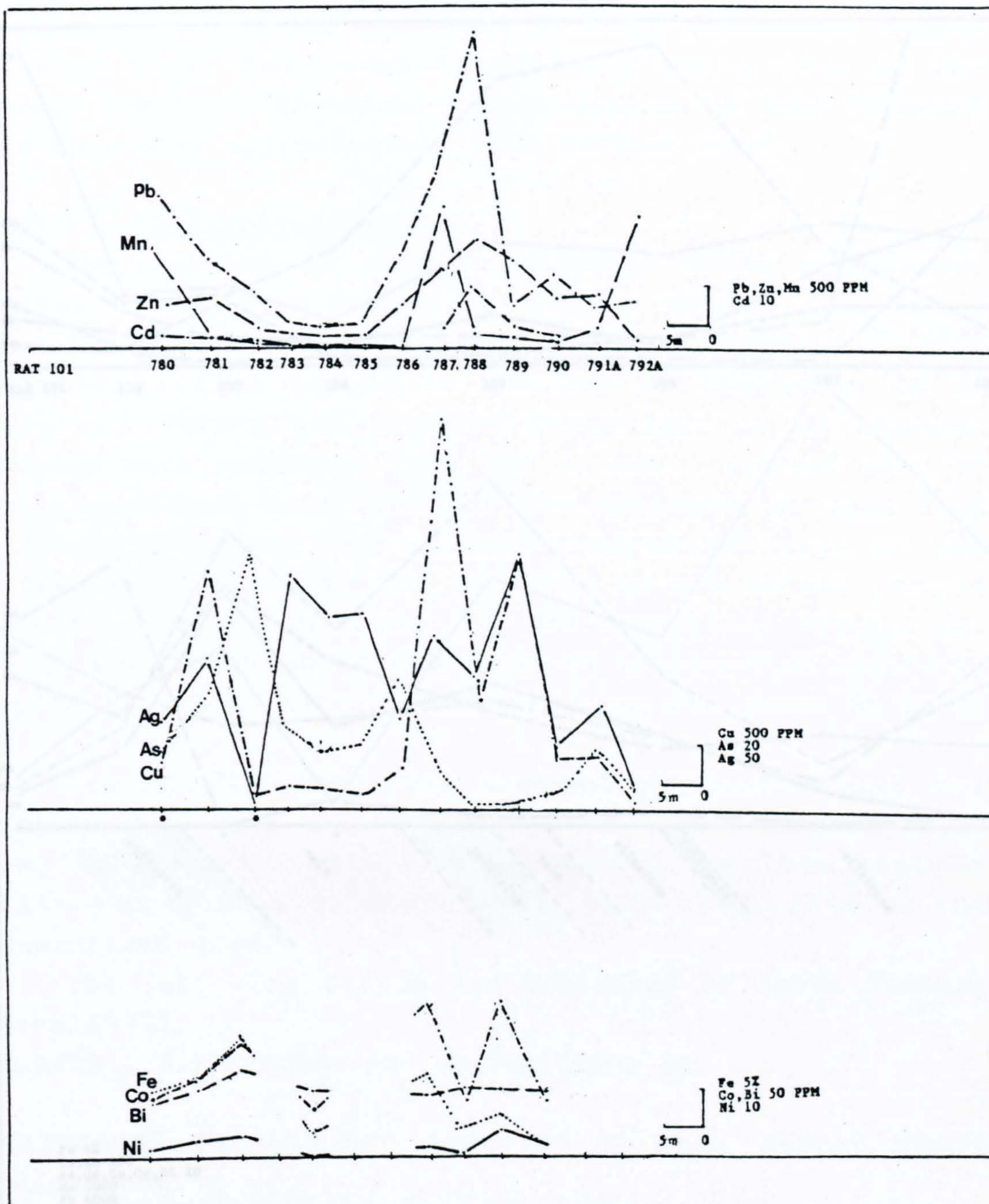
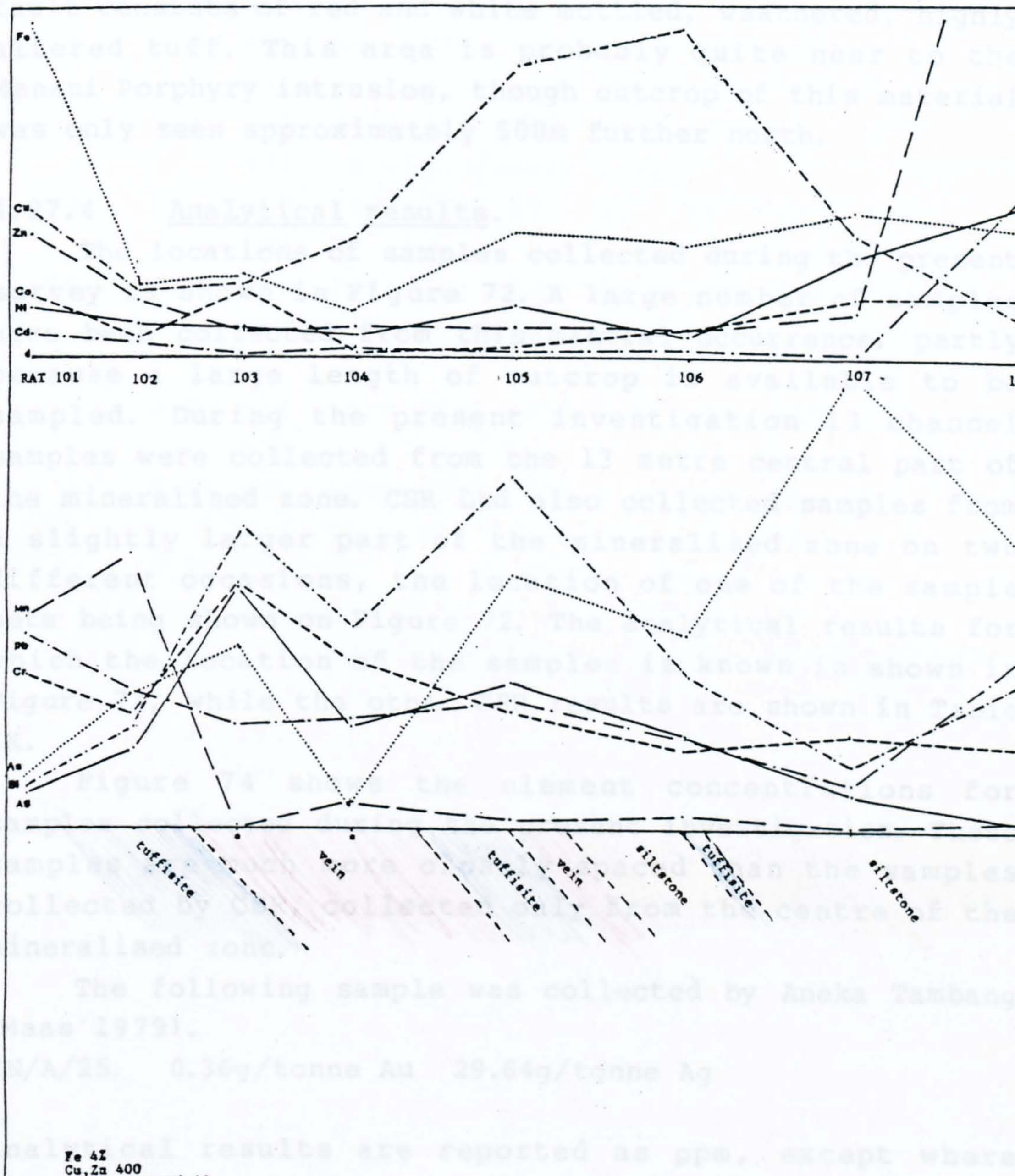


Figure 73. Analytical results for the Rambutan Tinggi Vein.



Sample	Cu	Pb	Zn	Ni	Co	Cd	Mn	Fe%	Bi	Ag	As	Cr	Au	Sb	Sn
Ma R780	575	1950	560	2	71	3	1380	6.1	70	116	30	4	0.02		
781	3070	1160	660	4	88	3	185	7.8	100	193	60	3	-0.01		
782	175	740	256	5	115	2	72	12.2	150	10	130	2	0.02		
783	270	360	185				36			300	44		-0.05	4	-4
784	255	270	163	1	86	1	61	2.48	60	249	30	2	-0.01		
785	195	350	190				40			250	34		-0.05	-4	-4
786	510	1200	550				38			120	65		-0.05	8	55
787	4940	2260	1040	3	80	5	1830	8.2	200	226	19	2	-0.01		
788	1350	4010	3000	1	89	16	190	2.21	70	169	4.0	1	-0.01		
789	3270	650	1120	7	85	6	156	4.1	200	320	4.0	1	-0.01		
790	675	940	600	4	86	3	71	1.54	60	81	10	1	-0.01		
791A	680	540	440				270			135	32		-0.05	-4	50
792A	120	620	250				1700			32	12		-0.05	-4	70

Figure 74. Analytical results for the Rambutan Tinggi Vein, samples collected by CSR Ltd.



Sample	Cu	Pb	Zn	Ni	Co	Cd	Mn	Fe%	Bi	Ag	As	Cr	Au*
RAT 101	1440	1920	1200	12	15	5	5300	32.1	40	45	12	38	
102	650	1350	570	8	5	3	4870	7.2	100	100	33	28	-0.01
103	705	1020	253	7	17	1	68	8.4	300	370	45	61	0.02
104	1020	1080	310	5	1	2	650	4.6	200	127	5.5	42	0.03
105	2900	1270	307	13	7	2	6300	12.4	350	180	2.5	29	-0.01
106	3260	900	285	5	7	2	4870	11.2	150	114	3.5	20	-0.01
107	1210	460	440	25	14	1	1.14%	14.6	65	43	1.0	24	
108	375	1710	7200	38	15	41	7100	12.8	150	10	2.5	22	
109	106	810	170	5	2	1	134	5.2	15	18	44	21	
109	106	790	169	7	4	1	131	5.3	15	17	48	24	

the east consists of Telisa Formation dark mudstones. The hangingwall is not exposed, and to the north the vein is cut off by a fault. The lithology to the north of the fault consists of red and white mottled, weathered, highly altered tuff. This area is probably quite near to the Manani Porphyry intrusion, though outcrop of this material was only seen approximately 500m further north.

4.27.4 Analytical results.

The locations of samples collected during the present survey is shown in Figure 72. A large number of samples have been collected from this mineral occurrence, partly because a large length of outcrop is available to be sampled. During the present investigation 13 channel samples were collected from the 13 metre central part of the mineralised zone. CSR Ltd also collected samples from a slightly larger part of the mineralised zone on two different occasions, the location of one of the sample sets being shown on Figure 72. The analytical results for which the location of the samples is known is shown in Figure 73, while the other CSR results are shown in Table IX.

Figure 74 shows the element concentrations for samples collected during the present investigation. These samples are much more closely spaced than the samples collected by CSR, collected only from the centre of the mineralised zone.

The following sample was collected by Aneka Tambang (Maas 1979).

MN/A/25 0.36g/tonne Au 29.64g/tonne Ag

Analytical results are reported as ppm, except where indicatated.

The analytical results in Table IX and Figures 73 and 74 show that gold is present in small amounts in some of the samples, and the silver content is quite high. The higher gold content in the sample reported by Maas (1979), and the variation in gold content between the two sets of samples collected from the same area may be due to the irregular distribution of gold in veins at Mangani. Copper, lead and zinc are present in quite large amounts,

Table IX. Analytical results for the Rambutan Tinggi Vein, Samples collected by CSR Ltd, location unknown.

samp	Au	Ag	Cu	Pb	Zn	As	Bi	Mn	Mo ppm
A99655	0.03	310	680	475	385	21	50	120	3
	0.04	372							
56	0.04	48	640	810	495	19	30	1090	3
		47.8							
57	0.02	175	1310	610	280	36	50	78	1
		432	1m wide quartz zone.						
58	0.02	160	144	385	50	22	80	44	1
		168							
59	0.03	205	760	980	445	48	150	178	2
		288		0.25m wide quartz zone.					
60	0.02	220	1030	3160	1800	4.0	150	145	<1
		258							
	0.03	225	1080	3200	1790	4.0	140	150	1
72	0.05	5.1	91	45	1.10%	14	<0.5	290	3
	0.05	4.5	87	39	1.09%	14	<0.5	310	3
	Rock specimen								
73	0.04	110	2690	1400	610	3.5	150	7030	3
		131							
74	0.02	93	540	700	435	22	65	63	2
		130							
75	0.03	132	101	420	114	110	30	58	2
		234							

the highest zinc content being just over 1%. Arsenic is present in moderate amounts, but the bismuth content is high. A number of the samples contain a quite high manganese content. There appears to be no great correlation between the presence of an obvious quartz reef and high element contents, the highly mineralised sediments and tuff dykes often containing higher element concentrations. Ni and Co and Cd are present in only very small amounts, suggesting that the correlation between Cd and Zn seen in the soil and stream sediment survey is not present in this type of mineralisation. The very high pyrite content of some of the samples is reflected in the high iron contents.

Samples were collected at an oblique angle to the mineralised zone, and the high variability of element concentration across this zone suggests that the distribution of metals is just as irregular along veins, as across veins. The high degree of variation is especially evident in the more closely spaced samples across the centre of the mineralised zone (Fig. 73).

4.27.5 Petrology.

4 polished sections from this vein were examined. Some of the samples consisted entirely of quartz, with large interlocking grains, and a few scattered pyrite crystals. Thin irregular zones of brecciation indicate that later deformation occurred. In other samples angular fine grained clasts are cemented by quartz, and probably consist of completely silicified Telisa Formation mudstones. In other specimens, textures suggestive of altered tuffaceous material can be seen. Small irregular shaped fluid inclusions are common, but rarely contain gas bubbles, suggesting that most have undergone remobilisation.

The sulphide material present includes arsenopyrite, pyrite and sphalerite in chalcopyrite. Unlike other veins chalcopyrite is common as large grains, rather than as small inclusions in other minerals. Sphalerite in this vein does not often contain chalcopyrite inclusions, possibly suggesting that the chalcopyrite has been remobilised. The pyrite and arsenopyrite occur as angular grains, while the sphalerite occurs as rounded blebs. Some larger early pyrite grains are also present. Some of the galena appears to be replacing the chalcopyrite, and late veinlets of chalcopyrite and galena are present. Some of the larger grains of sphalerite replace the chalcopyrite.

4.28 Rumah Sakit Vein (Hospital, Baroe)

4.28.1 Introduction.

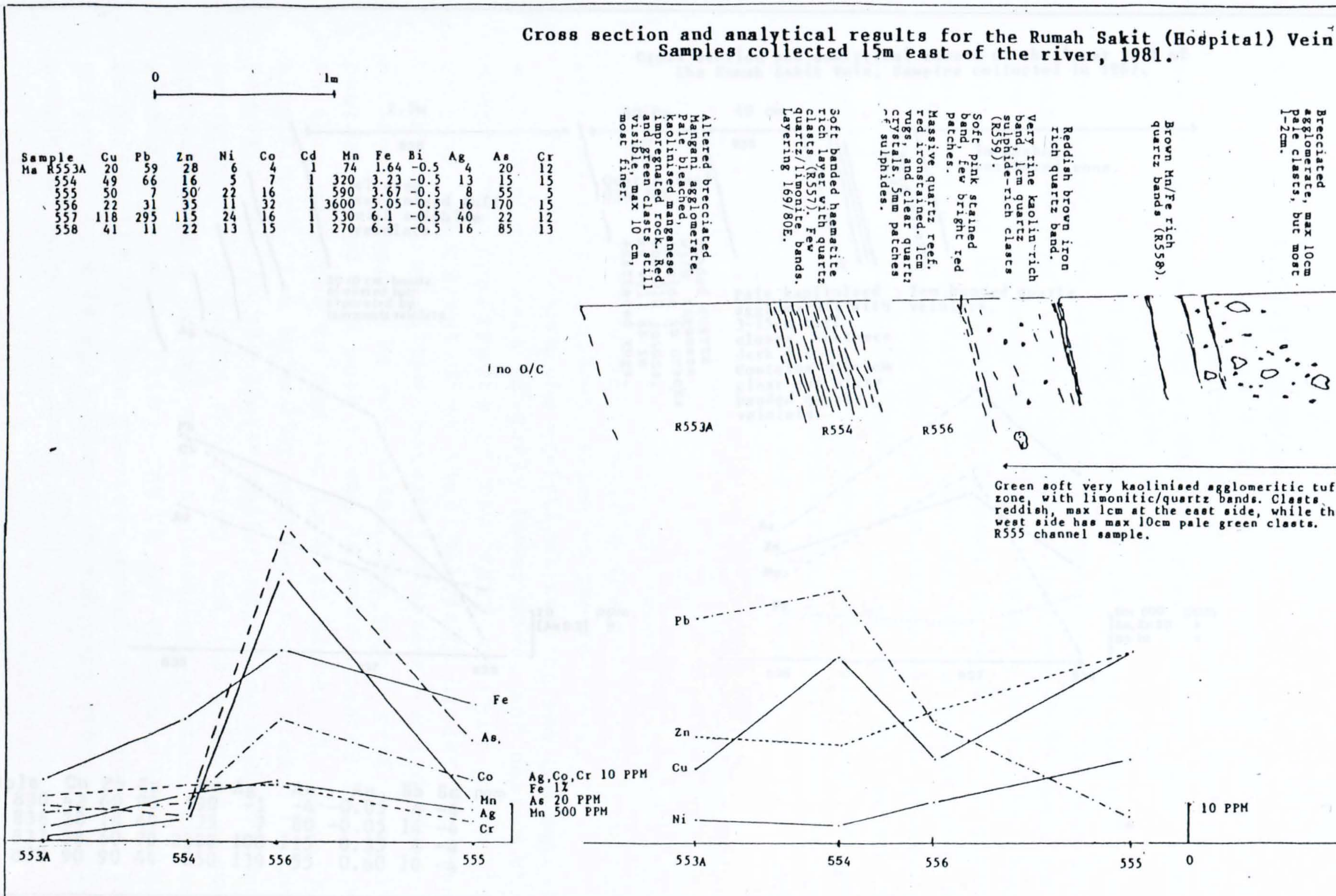
The Rumah Sakit Vein is Located in the eastern branch of the A. Poengoetan (Rumah Sakit or Hospital stream), about 400m from the Mangani-Rambutan road. This vein was known from the time of the first prospectors. In 1921 M.M. Aequator reported that good analytical results (values not stated), were overshadowed by the discovery of Rumput Pait. In December 1922 Ir. Verhof was engaged to prospect between the A. Galanggang, and the eastern concession edge, and in 1925 and 1926 analytical results from the eastern side were reported. The name of the vein was derived from the presence further downstream of the mine hospital. During the present investigation this vein was sampled on a number of occasions, as a landslide had cleared a section about 15m east of the river, and later the local people cleared a section nearer the river for mining.

4.28.2 Geology and structure.

The orientation of the vein is 030/75-80^{o}E. The mineralised zone is about 5m in width, though the width of the quartz reef itself does not exceed 2.5m.

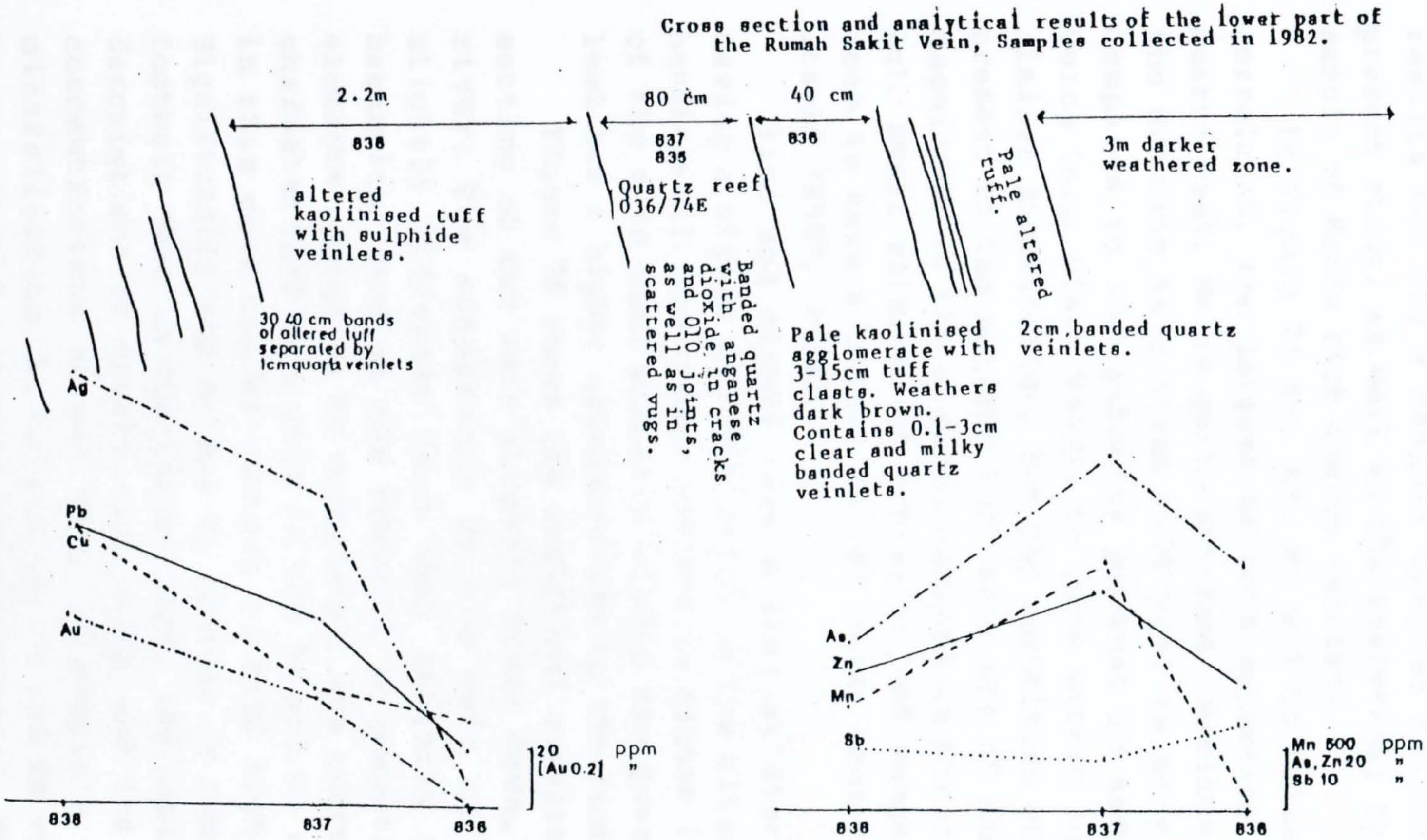
The vein is hosted in tuffs and andesites. Figures 75 and 76 show the nature of the host rock, which in general consists of different types of brecciated kaolinised and silicified tuff, veined by thin quartz veinlets. Some of the tuff is recognisable as red and green agglomerate of the Mangani Volcanic Formation. The vein could be followed for about 30m to the east as a trail of quartz fragments in pale kaolin-rich soil, in a water gulley dug by local miners to divert water away from their adit.

The west river bank is buried under deep rubble, and the vein can not be found there, though tunnel 31 dug slightly upstream in firmer rock by M.M. Aequator found



Sample	Cu	Pb	Zn	Ni	Co	Cd	Mn	Fe	Bi	Ag	As	Cr
Ma R553A	20	59	28	6	4	1	74	1.64	-0.5	4	20	12
554	49	66	16	5	7	1	320	3.23	-0.5	13	15	15
555	50	7	50	22	16	1	590	3.67	-0.5	8	55	5
556	22	31	35	11	32	1	3600	5.05	-0.5	16	170	15
557	118	295	115	24	16	1	530	6.1	-0.5	40	22	12
558	41	11	22	13	15	1	270	6.3	-0.5	16	85	13

Figure 75. Cross section and analytical results for the Rumah Sakit (Hospital) Vein. Samples collected near the river, 1981.



Sample	Cu	Pb	Zn	Mn	Ag	As	Au	Sb	Sn ppm
830	42	60	90	990	-1	-4	-0.05	4	-4
836	28	18	40	75	7	80	-0.05	14	-4
837	38	60	70	2000	100	115	0.35	8	-4
838	90	90	44	850	139	55	0.60	10	-4

Figure 76. Cross section and analytical results, samples collected 1982.

sediments, suggesting that the vein is truncated by a fault.

4.28.3 Analytical results.

Figures 75 and 76 show the location and analytical results for the 9 channel samples collected during the present study, as well as the analytical result for a grab sample of Mn/Fe rich quartz veinlets.

In Figure 75 Fe, As, Mn and Co values appear to be correlated, the largest amounts occurring in the massive quartz reef. Mn is quite abundant (maximum 3600 ppm), but the maximum As content (170 ppm) is only moderate when compared to the quantity present in some of the other veins (e.g. Linda Vein). To some extent Ag and Cr show a similar distribution, but the quantities of these elements present in the altered tuff zone are of the same order of magnitude as the element content in the vein (max 16 ppm Ag). Small veinlets of limonitic and manganiferous quartz seem to have a higher silver value than the quartz reef itself (R557, R558).

Zinc and nickel have a similar distribution, both having a higher concentration in the altered tuff in the hangingwall. The copper content is higher in the wall rock of the vein than actually within the quartz reef, while lead has a higher concentration in the footwall.

Figure 76 shows the analytical results and geological setting of the vein slightly lower down, and nearer the river. The appearance of the vein at this point is slightly different from that slightly higher up. The haematitic band at the footwall is absent, and different elements appear to be correlated. The quartz reef is again characterised by a peak in the As and Mn content, though in this case the Zn content is also higher in the vein. Significantly the Au and Ag content is much higher in the footwall than in the quartz reef, indicating that written descriptions of quartz reef width and its precious metal concentrations do not give an adequate picture of the mineralisation. At this point Cu and Pb values appear to be correlated with the precious metal. Sb is present in this vein (max 14 ppm), but does not vary significantly across the mineralised zone.

The Hospital Vein was investigated by M.M. Aequator with a number of short tunnels.

east bank T 46

sample		width (m)	Au ppm	Ag ppm
river side		1.8	2	635
cross cut	2	worthless		
	3	2m	trace	92.5
	4	1.25	trace	162
	5	1.6	0.5	448
	6 (1925)	1	0.4	195
cross cut	6 (1926)	2.1	0.2	65.4
	7	3	0.1	112.5
	8	2.75	0.9	190.4
	9	1.25	3.2	258
	10	1	0.2	47
	11	2.75	0.3	324
	12	1	trace	25

The following analytical results are reported by Maas (1979).

MN/A/12	0.27g/tonne Au	529g/tonne Ag
MN/A/13	1.00	160.80
MN/A/14	0.48	34.16
MN/A/15	1.7	188.62

CSR Ltd also collected samples from this vein. The following values are in ppm, unless otherwise stated.

No	Au	Ag	Cu	Pb	Zn	As	Bi	Mn	Mo ppm
A99666	2.3	60	60	76	70	24	<0.5	2.42%	1
	3.57	332							
67	1.71	61	39	124	57	7.0	"	10910	1
	1.58	244							
68	1.24	175	33	33	50	4.5	"	2.13%	2
	1.75	202							
69	1.65	88	61	102	73	16	"	4920	1
	3.23	256							
70	11.7	89	58	146	47	7.0	"	1270	1
	8.96	632	20m above adit						
71	0.30	102	37	34	28	220	"	365	1
	0.07	113							

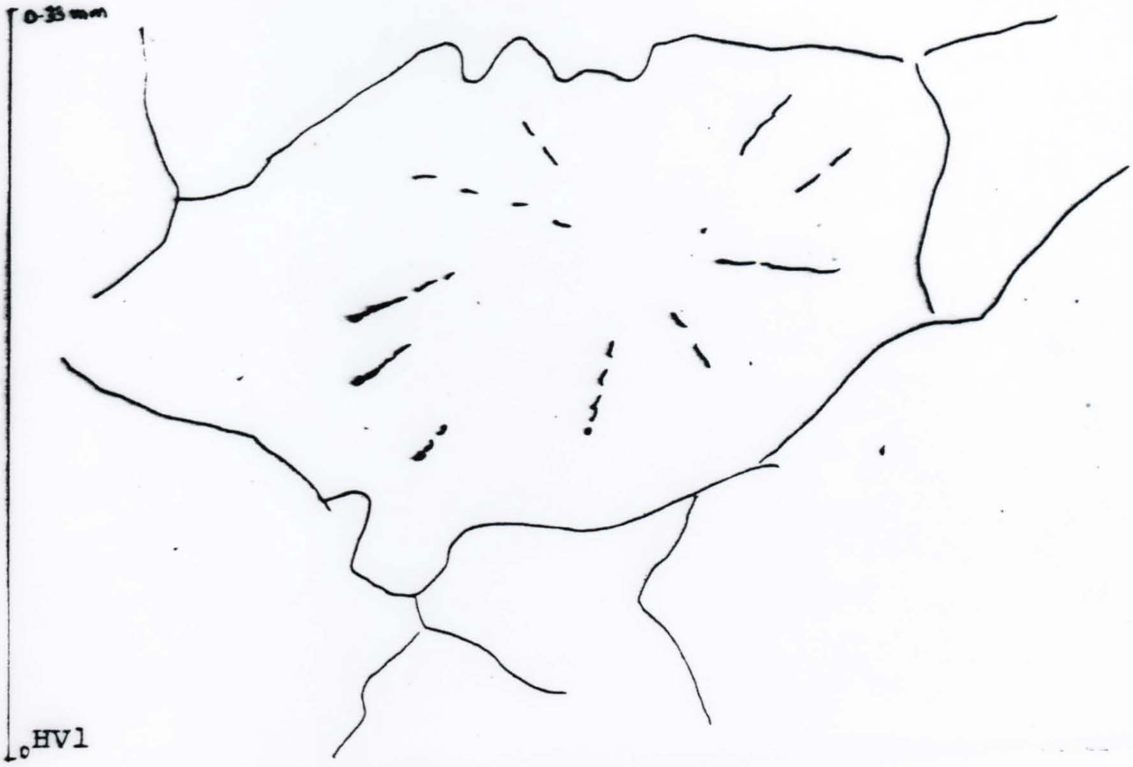
The analytical results indicate that gold is present in this vein in quite appreciable amounts, as well as silver. These samples were analysed in duplicate for the precious metals at different analytical laboratories, the high variability suggesting that some of the other analytical results discussed in this text may show a similar high variability. Base metal sulphides and Mn, Co and Ni appear to be present in only moderate amounts, though the chromium content is higher than in other veins. As is present in significant amounts, but Bi is absent, and Cd very low. Like other veins in this area the Mo content is negligible. The exact location of the CSR samples is not known, but they contain a larger amount of Mn and Au than some of the samples collected during the present study.

4.28.4 Petrology

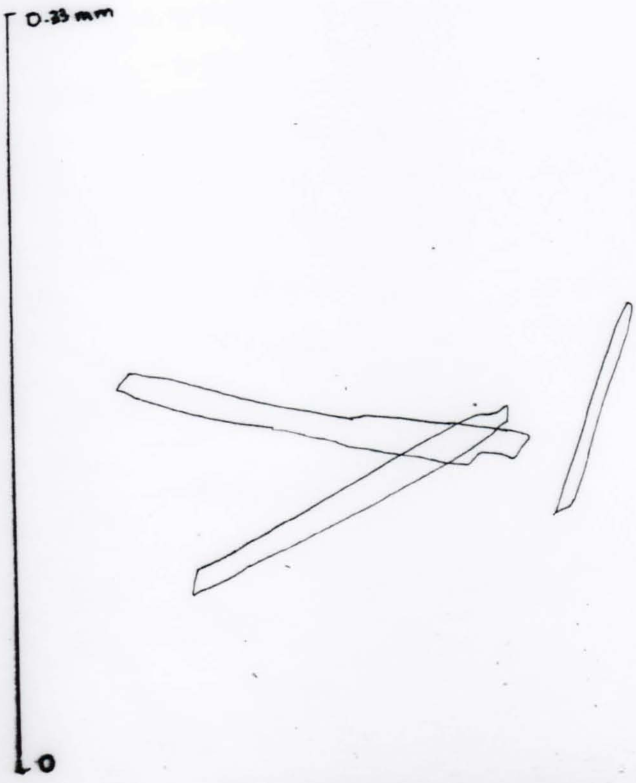
5 polished sections from this vein were examined. The quartz reef consists of recrystalised interlocking quartz patches, with very abundant fluid inclusions in a radial pattern (Plate 24a). In some cases the remains of an earlier finer fabric can be seen. Cross cutting veinlets of quartz crystals also contain fluid inclusions, but these are larger, and more regular in shape, sometimes containing a gas bubble. The centres of quartz veinlets may be filled with large calcite crystals, or a void. Calcite is later than quartz, as locally abundant calcite occurs replacing quartz. Some of the banded quartz and manganese shows cockcomb texture, and may have formed as a space filling vein, rather than by replacement.

Most recognisable sulphidic material consists of pyrite and some chalcopyrite, occurring as thin veinlets. Often a single veinlet will consist of separate bands of these minerals, together with bands of haematitic material, where pyrite has been affected by weathering. Scattered pyrite crystals are also sometimes present, with small rounded inclusions of pyrrhotite.

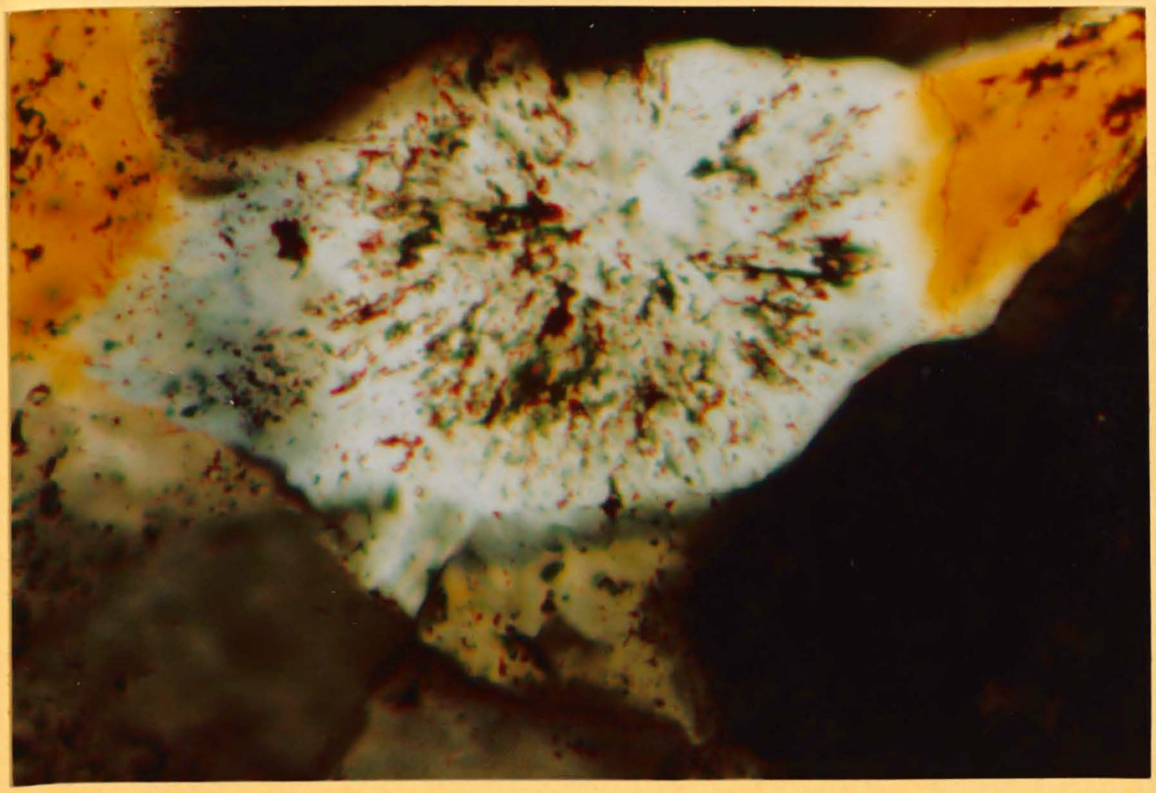
A number of float samples with more abundant sulphides were found just downstream from this vein, and contain early pyrite with an almost framboidal texture, possibly formed as a result of brecciation. Later large pyrite crystals are partly replaced by chalcopyrite, which also rims sphalerite containing a few chalcopyrite and

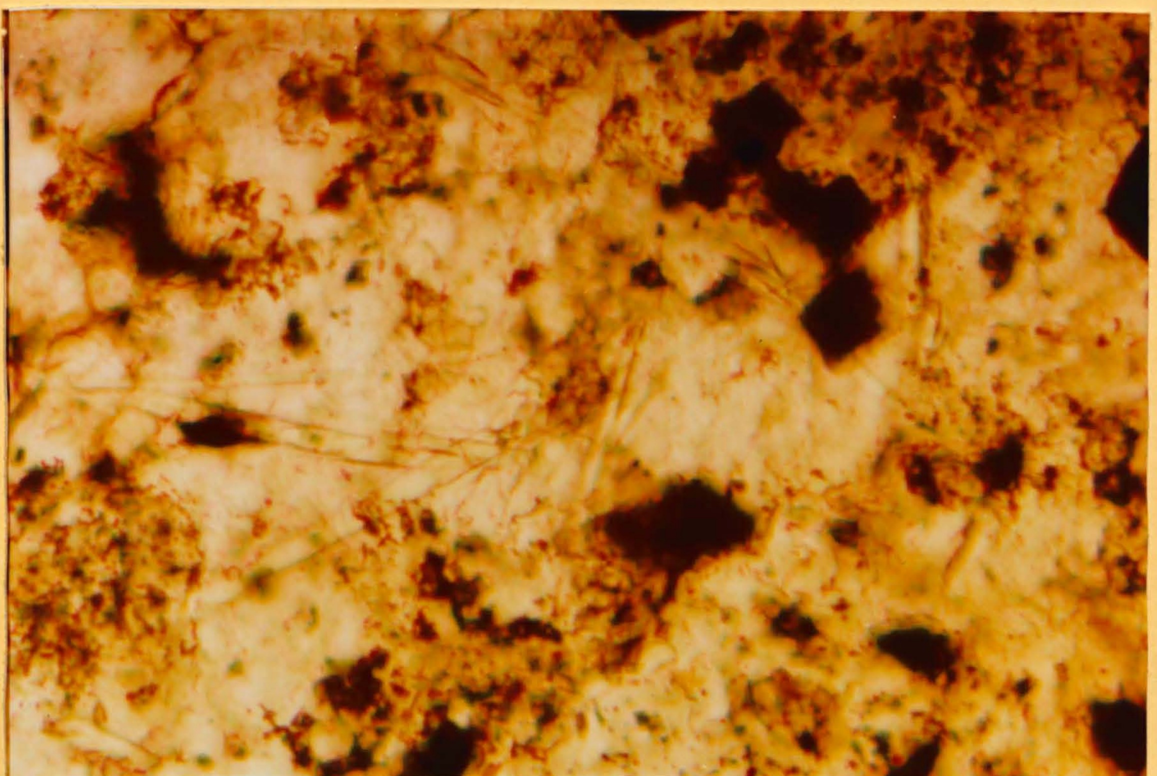


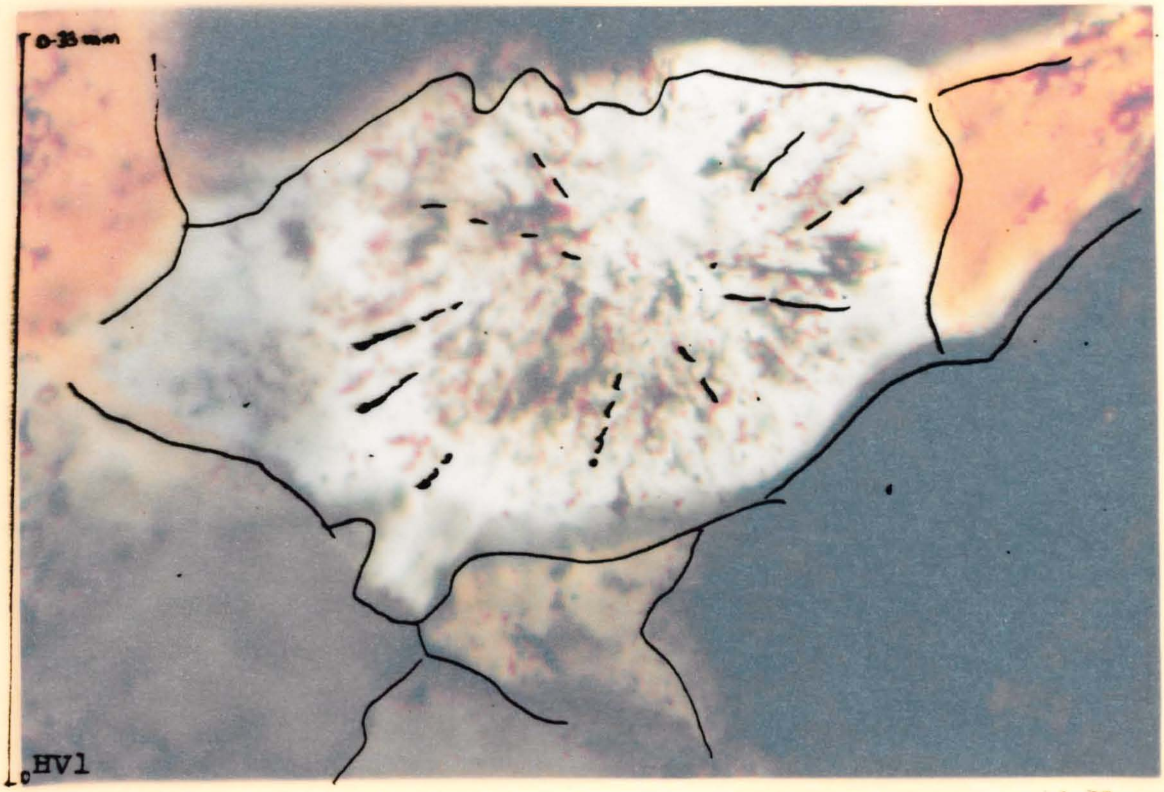
a. Photomicrograph of a thin section of gangue from the Hospital (Rumah Sakit) Vein, showing radially arranged fluid inclusions.



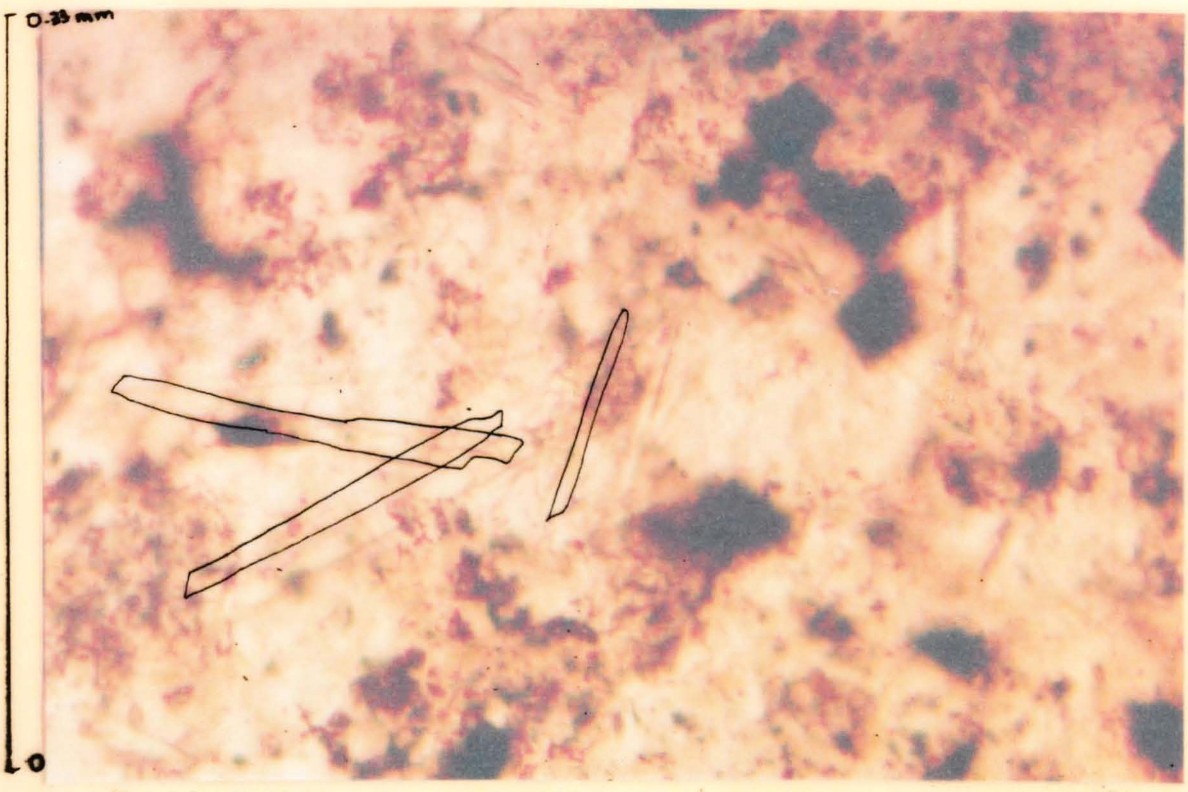
b. Photomicrograph of a thin section from the Eastern Vein (Ma R826), showing needles of calcite, possibly replacing aragonite.







a. Photomicrograph of a thin section of gangue from the Hospital (Rumah Sakit) Vein, showing radially arranged fluid inclusions.



b. Photomicrograph of a thin section from the Eastern Vein (Ma R826), showing needles of calcite, possibly replacing aragonite.

pyrite inclusions. Smaller chalcopyrite blebs in straight rows are also present (chalcopyrite disease). Galena is present, and both rims, and is rimmed and replaced by chalcopyrite, suggesting that chalcopyrite was being deposited over a long time period.

4.29 Rainmaker (Rumah Potong Kiri) Vein

4.29.1 Introduction.

This vein was discovered during the present investigation, and is not mentioned in any literature. Little work was done at this location, as five visits were made to this area, and each time heavy rain started falling immediately.

4.29.2 Geological details.

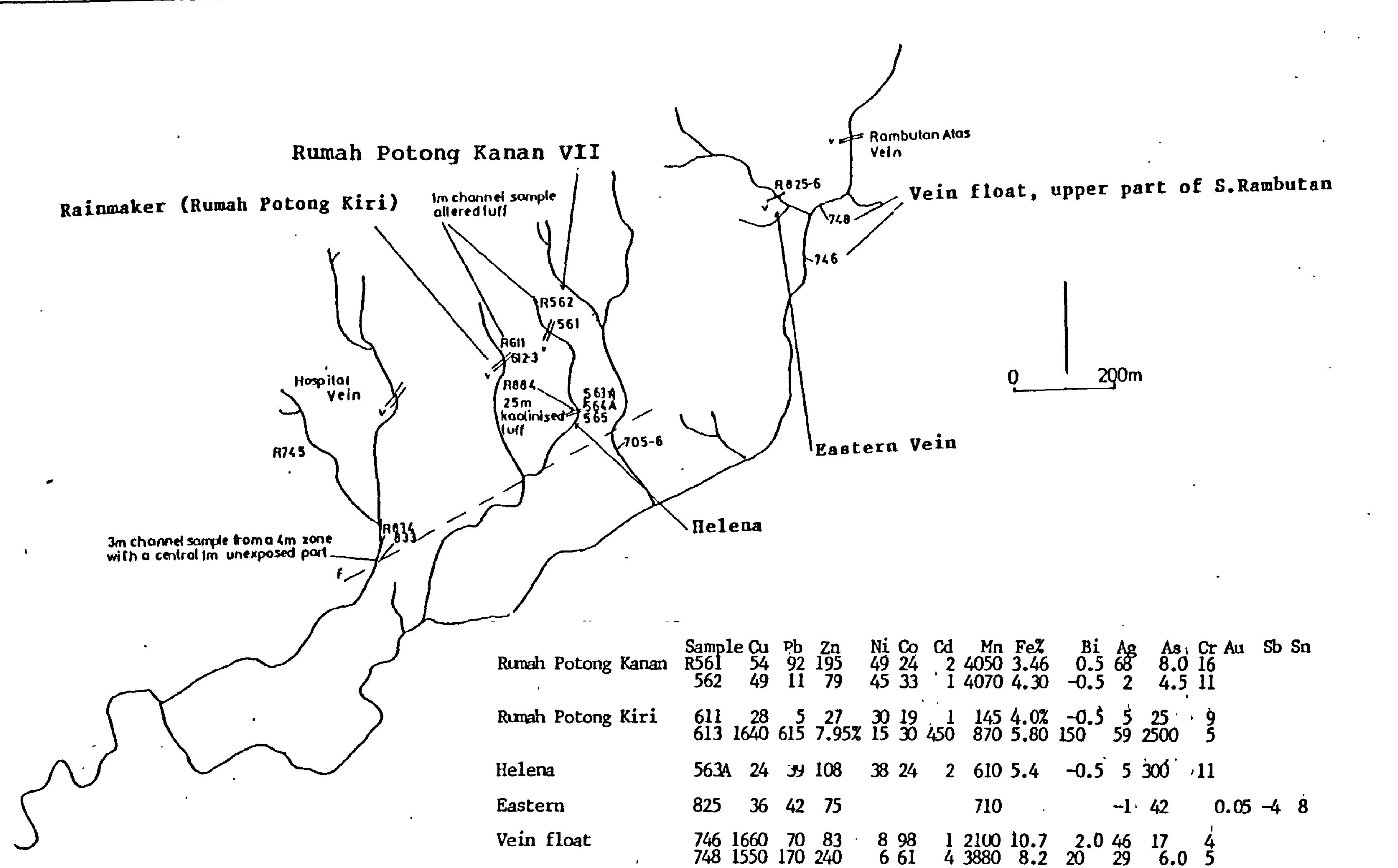
This vein is oriented 040/80^{o}S, and is 90cm wide, with a 60 cm kaolin and sulphide zone with green Cu staining on the footwall side.

Weathered tuffaceous material forms the host rock to this vein. Enclosure 2 shows the geology of this area.

4.29.3 Mineralisation

Figure 77 shows the locations of samples collected from this vein, and other veins to the east, and their analytical results. The outcrop consists of a fairly massive quartz reef, with some manganese staining, and disseminated pyrite, with an altered footwall zone also being exposed. A channel sample across the vein was collected, as well as a sample of the wallrock exposed to the north of the vein.

The chemical analyses of the wall rock on the footwall side show that the base metal and manganese content is fairly low. The high iron content is probably the result of the pyritisation. Silver is present both in the wallrock and the vein, and the arsenic content of the wallrock is similar to that seen in some of the other veins. The vein has a high zinc content, despite pyrite being the most common visible sulphide. All elements except Ni are much more abundant in the vein than in the



	Sample	Cu	Pb	Zn	Ni	Co	Cd	Mn	Fe%	Bi	Ag	As	Cr	Au	Sb	Sn
Rumah Potong Kanan	R561	54	92	195	49	24	2	4050	3.46	0.5	68	8.0	16			
	562	49	11	79	45	33	1	4070	4.30	-0.5	2	4.5	11			
Rumah Potong Kiri	611	28	5	27	30	19	1	145	4.0%	-0.5	5	25	9			
	613	1640	615	7.95%	15	30	450	870	5.80	150	59	2500	5			
Helena	563A	24	39	108	38	24	2	610	5.4	-0.5	5	300	11			
Eastern	825	36	42	75				710			-1	42		0.05	-4	8
Vein float	746	1660	70	83	8	98	1	2100	10.7	2.0	46	17	4			
	748	1550	170	240	6	61	4	3880	8.2	20	29	6.0	5			

Figure 77. Analytical results and location of samples of mineralised material from the Rambutan Atas-Hospital Vein area.

wall rock, with high Bi (150 ppm), and As (2500 ppm) contents. Ag is present in quite high amounts (59 ppm).

4.30 Rumah Potong Kanan Vein

4.30.1 Introduction.

This vein was discovered during the present investigation, and is not mentioned in any of the literature.

4.30.2 Geology

The geological map of Mangani (Enclosure 2) shows the details of the geology of this area, though generally outcrop is scarce in these smaller streams. The vein itself outcrops for 4.5m along the stream, with a 30cm eroded gap between the footwall and the next outcrop of blue-grey fine grained tuff. This gap may be caused by an eroded kaolin band. The orientation of this vein is 020/75^{o}E, and the width varies from 1.0-1.2m.

4.30.3 Mineralisation

Figure 77 shows the location of samples from this area, and analytical results. A channel sample was collected across the vein, as well as a 1m sample of the wallrock on the north side of the vein. The vein consists of quite massive white quartz with a small amount of disseminated pyrite, and some dendritic manganese oxides along fractures. In thin section interlocking quartz grains with some fluid inclusions overgrow an earlier finer material. Cross cutting quartz veinlets contain pyrite crystals, but no other sulphides were seen.

Analytical results show that only small amounts of base metals are present in this vein, with even lower amounts in the wallrock. Co and Fe are the only elements which are more abundant in the wallrock than the vein, with the iron probably occurring as pyrite. The manganese content of the vein and wallrock is similar, and high (~4000ppm). Bi is almost absent, and As is low. These characteristics are very different from the Rainmaker Vein, which is only about 150m to the west, and is probably part of the same fracture system. An alternative explanation is that these veins are not continuous, but form part of an en echelon set of veins.

4.31 Helena Vein

4.31.1 Introduction:- This vein was discovered during the present investigation, and is not mentioned in the literature, or known to the local people, who after its discovery promptly investigated its mining potential!

4.31.2 Geological details.

Details of the geology of this area are shown on the geological map (Enclosure 2). A vein width of 1m is exposed, but the vein may be wider. The orientation is 085, vertical. Most of the outcrop in the area consists of Mangani Volcanics (red and green agglomerates and tuffs, and some andesitic lavas).

4.31.3 Mineralisation

This vein is very similar in appearance to the Rumah Sakit Vein, consisting of a hard quartz vein with disseminated sulphides, and thin sulphide veinlets. In some places kaolin-rich patches may be the remains of clasts of volcanic rock. Later cross cutting veinlets of clear quartz of 0.5-1cm width occur.

4.31.4 Analytical results

A channel sample across the vein exposed in a small side stream was initially collected. The wallrock at this point is not exposed. Later a channel sample across a 1m width of vein on the western bank of the stream exposed as a result of local mining, was collected (Ma R884). The analytical results and locations of samples are shown in Figure 76. Most element contents are moderate, except the arsenic content which is high (300 ppm). A small amount of silver is present (5 ppm). The moderately high iron content (5.4%) is probably mainly present as disseminated pyrite and possibly arsenopyrite.

4.32 Eastern Vein

4.32.1 Introduction.

This vein was discovered during the present investigation, and is located in the fourth large stream east of the camp (Kampung Jawa).

4.32.2 Geological details

The geological map of the area (Enclosure 2) shows details of the geological setting of this vein. The vein consists of a silicified kaolin band exposed in a waterfall. Some disseminated pyrite is present, but generally there is no other evidence of mineralisation. Examination of thin sections showed that needles were present, partly altered to carbonate (Plate 24b). A similar texture is reported from the Mangani Vein by Schouten (in De Haan et al., 1933), who suggested that the intermediate form of the calcite deposited during the hydrothermal alteration at Mangani may have been aragonite in some cases.

The vein is oriented 008/62^{o}E, and a width of 80 cm is exposed.

4.32.3 Analytical results

A channel sample across the width of the vein (80cm) was collected. The analytical results are shown in Figure 76. Most elements only occur in small amounts, but significantly arsenic levels are moderately high, and a small amount of gold is present, though silver is below the detection limits. This suggests that larger amounts of precious metals may be present in other parts of the vein. Some tin is present, but antimony is below the detection limit. The manganese content is moderate.

4.33 Pagadis

4.33.1 Introduction

This mineralisation is located on the south east flanks of Bukit Guntung (Fig. 5).

No work was done during the present investigation in the Pagadis area, but details of this occurrence are included as some of the geochemical anomalies in the south-east of the area may be derived from Pagadis or similar mineralisation, and M.M. Aequator annual reports contain details of analytical results which explain why so much interest was given to this occurrence.

The Pagadis mineralisation is mentioned in the M.M Aequator report of 1922, and discussed by De Haan (1948). Apparently this was one of the first areas in Indonesia where geophysical methods were tried, but the results of this work cannot be traced. A large number of adits were dug into the mountain at various points but no workable ore was ever found.

4.33.2 Geology and mineralisation.

According to De Haan (1948), blocks of ore were found in volcanics, some with high gold contents. The blocks are found over quite a large area, and were initially thought to be the result of a large fossil landslide, though later it was thought that this was a large fault zone, or an igneous breccia, with ore blocks as clasts in basalt.
M.M. Aequator annual mining reports contained the following analytical results from this area, a number of samples containing quite high amounts of silver.

sample	59	1.8g/tonne Au	288g/tonne Ag
	60	0.5	75
	61	0.4	50
	62	0.8	148
	63	2.3	2596
	66	12.3	1638
	67	4.3	4295

4.34 Analytical results not discussed previously.

Table X shows the analytical results for rock samples from the Mangani area, and notes on the appearance and location of these samples. The exact location of these samples is shown on the map in Appendix B. Unless otherwise stated, samples are grab samples. Most of the following samples have been examined in thin section, but unless otherwise stated, show alteration phenomena similar to those described in Chapter 2, though many of these samples are some of the most highly altered rocks seen at Mangani.

4.34.1 Analytical results for altered tuffs.

a. R501, a weathered altered tuff from the south bank of the Galanggang Kiri contains more copper than many vein samples. The high iron and arsenic content is probably due to the presence of arsenopyrite and pyrite. This area has not been investigated in detail during the present study, but possibly the northern extension of the Mangani Vein is located near this area, though the manganese content in this sample is not very high. Alternatively the high Cu content is derived fron disseminated chalcopyrite, suggesting that this area should be examined in more detail.

b. Ma R521 and 522 were collected from trenches on Bukit Bulat, and though very weathered, appear to be mineralised. Ma R521 contains an appreciable zinc content (6150 ppm), and the manganese content is also quite high (1100 ppm). Ma R522 is not as mineralised, but both samples contain detectable silver (1-2 ppm). The arsenic content is surprisingly low, as often mineralised samples contain high concentrations of this element. The Bukit Bulat area has been examined further using geophysical and geochemical methods (Chapter 5).

c. Ma R702 is a float sample of highly altered feldspar porphyry collected just above the Johanna Vein, but except for its high arsenic content is unexceptional.

d. In the S. Jeanne, a 25m zone of highly altered, kaolinised tuff contained patches and bands of disseminated sulphides (0.5-1mm wide, trending 030^{o}). This zone is approximately along strike from the Helena Vein.

Analytical results for rock samples from the Mangani area

Sample	Cu	Pb	Zn	Ni	Co	Cd	Mn	Fe%	Bi	Ag	As	Cr	Au	Sb	Sn	Notes
Ma R501	138	15	35	4	8	1	200	5.8	-0.5	-1	37	5				Altered weathered tuff S of Galanggang Kiri
521	22	21	6150	46	16	4	1100	4.10	-0.5	2	1.0	18				Rock in trench at S516
522	4	16	150	5	8	1	690	2.14	-0.5	1	1.5	2				" " " at S112
702	5	31	25	4	22	1	127	3.21	-0.05	-1	410	6				Float near Johanna Vein
705	16	14	75				650			-1	80		-0.05	10	10	S. Jeanne, altrd rk, abundant diss sulphide
706	30	20	48				28			-1	105		-0.05	8	4	
745	60	13	79	89	52	2	860	6.7	-0.05	-1	9.0	30				Side strm to A. Rumah S. grn+white+gry tuff
765	6	24	130				330			-1	10		-0.05	-4	-4	Mangani porphyry
810	590	1.45%	1.45%				2.65%			21	60		0.05	16	80	A. Rumput Pait, Telisa Fmt + slphd veinlets
811	4	28	36				200			2	150		0.20	16	8	" " ", First Wf. Mangani North Vein?
812	6	40	55				340			1	130		-0.05	4	-4	" " ". 2nd Wf " " "?
833	185	36	160				1050			2	26		-0.05	4	10	Altered rock? vein? above bridge S. Rumah Sakit
834	14	32	75				1250			-1	10		-0.05	-4	6	Mangani breccia, " " " " " ".
839	20	28	34				65			1	130		-0.05	6	-4	S. Botung, altered tuff, patches diss As-Py
849	32	28	70				750			-1	18		-0.05	4	18	nd kaolin band, S. Botung.

Two channel samples were collected (MA R705, Ma R706) approximately 20m apart, both being collected from 60cm of outcrop approximately across the banding. Both samples contain quite a high arsenic content, suggesting that most of the visible sulphide is arsenopyrite. The concentrations of the other elements analysed are not particularly high, with gold and silver below the detection limit (<0.05 and <1ppm), but antimony and tin, both elements common in the Mangani Vein, are present in small amounts.

e. A sample of grey, green and white mottled altered tuff was collected approximately along strike from the Rumah Sakit (Hospital) Vein, in the western branch of the A. Rumah Sakit. Despite the green colour, copper is not particularly abundant (60 ppm), though this value is higher than that found in most other rocks. The Zn, Ni, Co and Cr contents are also higher than average (130, 80, 52 and 30 ppm). The significance of high values of elements normally associated with basic and ultra-basic rocks is not clear. Stephenson et al. (1982) report that the Mangani area has a regional anomaly for Co, Cu, Cr and Ni, and in other parts of Sumatra such anomalies are associated with serpentinite. The manganese and arsenic contents are not exceptional, and the bismuth and silver contents are below the detection limit (<0.5 and <1 ppm).

f. In the S. Botung, not far from the junction with the S. Rambutan, patches of disseminated grey sulphide (arsenopyrite?) occur in altered pale grey lithic tuff. The base metal and manganese contents are low, but silver is detectable (1ppm), and the arsenic content is high (130ppm). Sb is also present (4ppm), and is one of the elements associated with the Mangani Vein mineralisation.

4.34.2 <u>Analytical results for rock samples (except tuffs)</u>.

a. A sample of Mangani Porphyry was collected from the upper part of the Rambutan River (S. Botung Lawas). Disseminated pyrite was visible in hand specimen, and in thin section feldspars could be seen to be altered. The analytical results were generally unexceptional, though the Zn content is quite high (130 ppm). Au, Ag, Sb and Sn were all below the detection limit, but some arsenic was present (10ppm). Since the rock was altered, it is not possible to state whether the Mangani Porphyry introduced some of the mineralisation into the Mangani area. Generally the rock is massive, with spaced jointing, suggesting that the rock may have been altered almost as soon as it was formed. This contrasts with the mode of alteration of the other rocks seen at Mangani, which are most altered near fault zones, where the brecciation has allowed penetration of fluids.

b. A sample of Mangani Breccia was collected just upstream of the road bridge over the A. Rumah Sakit (Fig. 77). Zn, As and Sn occurred in moderate amounts (75, 10 an 6 ppm), and manganese is quite abundant (1250 ppm). Silver, gold and antimony are all below the detection limit, suggesting that the mineralisation at Mangani is not directly connected with the formation of the Mangani Breccia.

4.34.3 <u>Analytical results for samples with sulphide veinlets</u>.

A number of such samples have already been described when they occur close to a vein, but a sample of Telisa Formation carbonaceous mudstone with abundant base metal sulphide veinlets was also collected from the A. Rumput Pait (Ma R810). This material may possibly be related to the Mangani North Vein, marked on the geological map published in De Haan et al. (1933). Pb, Zn and Mn are all very abundant (1.45%, 1.45% and 2.65%). Cu, Ag and Sb occur in moderate amounts (590, 21 and 16 ppm), and As and Sn are also abundant (60 and 80ppm). Only a small area of this material was exposed, but the presence of a small amount of gold (0.05 ppm) suggests that this area is potentially interesting, and should be investigated further to discover the extent of the mineralisation. Another possibility is that this is only a small area of mineralisation, but that it is indeed associated with a vein, in a similar way to the mineralised mudstone seen near the Eloise Vein.

4.34.4 Siliceous samples, possibly from vein outcrops.

In a number of cases, outcrops of siliceous material occurred, which were not immediately identifiable as vein material.

a. In the A. Rumput Pait, at approximately the point where the Mangani North Vein is marked on a map published in De Haan et al. (1933), large areas of very silicified, kaolin-bearing rocks were present. These rocks look like very silicified, bleached tuff, but could be part of a large vein. Ma R811 and 812 come from two localities, approximately 60m apart. Both samples contain only moderate amounts of base metal and manganese, but both samples have a high arsenic content (130-150 ppm), and a small amount of silver (1-2ppm), and antimony (4-16ppm). R811 contains some gold (0.2ppm) and tin (8ppm), suggesting that, whether this is a vein or not, this occurrence should be investigated further.

b. A sample of material, which looked like a highly silicified, bleached dyke(Ma R833), was collected just above the road bridge over the A. Rumah Sakit (Fig. 77). The rock was fine and equigranular, features not usually seen in veins in the Mangani area, but analytical results show the presence of higher than usual amounts of Cu, Zn and Mn (185, 160 and 1050 ppm). Moderate values of Ag, As, Sb and Sn are also present (2, 26, 4 and 10 ppm), though Au is below the detection limit (<0.05 ppm).

4.34.5 Kaolin bands.

Analytical results from a number of such bands have already been described where the kaolin is related to a vein. A thick (5m) kaolin band unconnected with any obvious mineralisation, but possibly related to the southern edge of the Mangani Graben, was collected from S. Botung (Ma R840). Base metals and manganese are present in moderate amounts, and some As, Sb and Sn are present (18, 8 and 18 ppm). Silver and gold are below the detection limit (< 1 and <0.05 ppm). These results suggest that this kaolin band formed as a result of alteration of a fault gouge, but that only minor amounts of valuable elements have been introduced during the alteration. One possibility is that several periods of hydrothermal alteration occurred, not all of them associated with valuable mineralisation. An alternative view is that many of the kaolin bands associated with known mineralisation only contain small amounts of valuable elements, so the lack of mineralistion in this kaolin band is in no way significant.

4.35 Relationships between known veins.

In the description of the different mineral veins, it has been pointed out that some of the veins may be extensions into an adjacent river valley of previously known veins. In addition, a number of fault trends are described, cutting the veins, and in some cases these trends could be interpreted in the light of the structure of the entire Mangani area (Chapter 2). In the following section some of these trends are summarised, in an attempt to relate the timing of the mineral deposition to the structural events in the area.

In the Rambutan-Silver Vein area, the geological map (Enclosure 3) shows that the possible norther~~e~~n extension of the Silver Vein into the Galanggang River is unaffected by the E-W faulting, while the possible northward extension of the Rambutan Vein has been cut into a number of sections, both by the E-W faults, and also by 050^{o} trending faults. This suggests that the Rambutan Vein is older than the Silver Vein. The E-W faults may be sinistral faults related to movement on the SFS, but the displacement appears to be dextral, suggesting that this may be apparent displacement caused by normal faulting related to tensional movement in the Mangani Graben. These features suggest that the main part of the mineralisation in the Rambutan Vein had formed before the Mangani Graben. The post-mineralisation faulting affecting the Rambutan Vein (described by Boomgaart, 1948) has already been summarised, and all the faulting affecting this vein appears to be related to tensional movement in the Mangani Graben.

The Rambutan-Silver Vein area is the only place where enough outcrop is present to enable the structure of the area to be examined, but the litareture relating to the Mangani area contains an extensive discussion of the relative displacements along the Boengsoe and Egert Faults, as the Mangani Vein contained rich ore right up to the place where it was cut by the Boengsoe Fault.

De Haan et al. (1933) argue that the Rumput Pait vein is the missing southern part of the Mangani Vein, using the following evidence.

Both veins have an older, barren quartz vein, and one or more periods of younger mineralisation, which result in the formation of exploitable ore. The later mineralisation is locally present in the Egert Zone, as well as clay bands and ore dragged along the fault. The composition and internal structure of clasts found near Rumput Pait resemble the Mangani Vein ore.

If the Egert Zone is the fault which removed the southern part of the Mangani Vein, then the Boengsoe Fault may also have removed a part of the vein, and a hidden portion of the vein may still be present.

Boomgaart (1948) published a map showing the relative positions of the different veins known at that time, at the same topographic level, and argued that the Brani Vein is the southern continuation of the Rumput Pait Vein, with the Sampil Vein as a footwall split. He considered that the Rambutan Vein is the southern continuation of the Mangani Vein. Similarities between the Mangani and Rambutan Veins include the presence of acid dyke rocks (feldspar porphyry?) at Rambutan, and the Mangani Northfield. If originally present in the Mangani South Field, these dykes are no longer recognisable due to alteration. Boomgart supposed that only vertical movement had occured on the Egert and Boengsoe Faults, and that movement had occurred simultaneously. A running argument developed, with De Haan publishing a reply to Boomgaart's article in the same journal, and also another article in 1949, where De Haan discounts most of Boomgaart's evidence. De Haan finally proposed that the Mangani and Rumput Pait are part of the same system, but that large horizontal movements had separated the veins. If this is the case, then the Rumput Pait Vein is a high level part of the southern part of the Mangani Vein, and rich mineralisation should extend to a greater depth than in the Mangani Vein.

I can not contribute to any of these arguments, as the evidence is all underground. Generally the outcrops of the Rumput Pait, Sampil and Brani Veins are all similar in appearance, though the precious metal content of the part of the Brani Vein sampled is lower. The outcrops of the Mangani and Rambutan Veins are not very similar in appearance, though this may be due to differences in the host rock.

The Egert Fault is probably related to movement on the SFS, and if this is the case movement on this fault should be dextral, which matches with the apparant diplacement between these veins. De Haan et al. (1933) describe a very long period of mineral deposition in the Mangani Vein, and it is entirely possible that the Rumput Pait and Mangani Veins were originally part of the same vein, but that after separation of the veins, both have been sites of later mineral deposition. Later mineralisation may have been deposited in the Mangani fracture system, resulting in the formation of the Rambutan Vein.

4.36 Summary of petrological details of veins in the Mangani area

In the first part of this chapter, the characteristics of each of the different veins, including a brief petrological summary, have been described. In this section, a summary of this information is presented, as well as some conclusions derived from the petrological examination of the Mangani veins.

The gangue of many of the veins grades almost imperceptably into the altered host rock, and there is no doubt that at least part of the bulk of many of the veins has formed as a result of total alteration of the rock along fault zones. The faults hosting the veins have not only provided a channel for the fluids responsible for the hydrothermal alteration, but also acted as a channel for the mineralising fluids. Fault movement continued throughout the period of formation of the veins, resulting in many generations of gangue recemented by later gangue. In most of the veins quartz is the main gangue material, though many veins contain late veinlets of carbonate, or patches of carbonate replacing earlier quartz. Often a generation of post-ore clear quartz veinlets is present. A number of veins also contain cockscomb and colloform quartz, suggesting that space-filling vein formation also occurred. Even when brecciated and mixed with rock fragments such material can be recognised by the lack of small inclusions, and the "clean" appearance.

Fluid inclusions are present in many of the veins, and in some veins are very abundant (e.g. the Rambutan Vein). The dirty appearance of quartz in some thin sections when examined under low power is caused by the great abundance of inclusions. The appearance of many of the fluid inclusions suggests that they have undergone remobilisation, and when using the criteria described by Roedder in Barnes (1979), these inclusions are considered to be secondary. This is not surprising when the mode of formation of these veins is considered, as material was probably being added over a long time period, and continually being re-brecciated by faulting. In some samples fluid inclusions of all sizes and shapes are present, with a great variation in the size of the gas bubbles in the inclusions. Kelly and Turneaure (1970) suggest that similar features from veins in Bolivia are caused by boiling. Boiling may well have occurred as a result of pressure release during faulting. The frequent presence of fluid inclusions in these samples suggests that detailed study of this material may allow the type of fluids involved in the deposition of this mineralisation to be determined, as well as giving some indication of the temperatures of deposition.

Sulphide minerals in the different veins generally show a similar sequence of deposition. There does not appear to be a marked difference in the sulphide minerals seen in the different veins, though the quantity of sulphide material is much larger in veins from the northern part of the Mangani area. The northern Mangani veins also sometimes contain quite appreciable pyrrhotite concentrations, though this mineral still occurs as an early phase. It is unlikely that the minerals described in the next paragraph were deposited as a result of a single phase of mineral deposition, but that the apparent paragenetic sequence is governed by the stability of one mineral relative to another, and its resistance to replacement. Replacement features are the most common textures seen in these veins. Pyrrhotite and arsenopyrite inclusions in other minerals may represent early higher temperature phases, but the remaining minerals were probably deposited during several periods of mineralisation.

Early arsenopyrite and pyrrhotite is partly replaced by a number of generations of later pyrite. Pyrite was deposited throughout the formation of the mineralisation, though much of the material may have been remobilised. Sphalerite either replaces, or rims pyrite. In some cases sphalerite contains abundant small chalcopyrite inclusions, but in other specimens these are rare, and when present they are larger. In specimens without abundant small chalcopyrite inclusions, chalcopyrite appears to have been deposited later, but it is likely that this chalcopyrite has been remobilised from the inclusions in sphalerite. Galena is thought to have been the last mineral deposited, as it is frequently seen replacing all the other minerals. Very small tetrahedrite grains have been seen in pyrite in some samples, but this mineral is very rare. Alabandite has been seen in float samples from the Mangani Vein, where it is partly replaced by carbonate. Many of the other veins contain a very high Mn content, but alabandite or Mn-bearing gangue (rhodonite, rhodochrosite) was not seen in these veins. Possibly this is due to the weathering, as in polished sections alabandite altered rapidly to Mn oxides. The Mangani Vein float was presumably derived from deep in the mine, and has only suffered forty years of weathering, while other vein outcrops have been weathered for much longer. Despite the presence of Bi, Sn and Sb, these elements do not form separate phases, though stannite is reported as small inclusions in sphalerite from the Mangani Vein (Kieft and Oen, 1974). Limited qualitative electron-microprobe work showed that the sphalerites sometimes contained tin, while the galena was bismuth or antimony bearing. Separate gold and silver phases were also not seen, and the silver presumably also occurs in the galena in many samples. Gold was not seen in polished sections, but presumably, if enough sections were examined, free gold or electrum grains would eventually be encountered. However, Boomgaart (1948) suggests that in the Rambutan Vein gold occurs as submicroscopic inclusions in pyrite, while De Haan et al. (1933) describe electrum from the Mangani Vein. Descriptions of the Mangani Vein ores include descriptions of many other mineral species. This suggests either that the Mangani Vein is different from the other veins, or that the availability of hand picked samples from many different parts of the mine enabled this more complicated paragenesis to be described.

The presence of arsenopyrite together with pyrrhotite and pyrite suggests that the temperature of formation of that assemblage could be calculated by measurement of the arsenic content of the arsenopyrite (Kretschmar and Scott, 1978). However it is considered that few of the mineral assemblages seen in the mineralisation at Mangani are in equilibrium, suggesting that results from such a geothermometer would probably not be valid.

4.37 Summary of the chemical characteristics of veins in the Mangani area,.

Table XI shows the maximum element contents encountered in samples from each of the veins. The different element contents have been used to divide the Mangani veins into the groups described in the next paragraphs. A table of average element content of Mangani veins has not been constructed as it is considered that such a table is misleading, since the total width of some of the veins has not been sampled, and the extreme variability of veins at Mangani means that only extensive drilling can indicate the value of any vein.

4.37.1 a) Base metal rich, Bi and Sn-bearing veins

The Linda, Eloise, Marah Selasa, Galanggang Black, Rambutan Atas, Rambutan Tinggi and Serassah Veins, as well as the Reinier/Gorge/Gulley Veins all contain a high base metal, Mn, As, Sn and Bi content. These veins also contain silver, though only a few veins contain a high average Ag content (e.g. Rambutan Tinggi). Generally the Sb content of such veins is quite low, though there are several

Table XI, Maximium element contents found in the different veins in the Mangani area

The following results are all in ppm, unless stated otherwise. This table gives no realistic indication of the value of the mineralisation, shows whether a particular element is abundant in that vein. If analytical results for a particular element are not available, but that element is reported to occur in that vein in the literature, or has been seen in polished sections, then the relevant column contains the word "yes".

	Vein	Au	Ag	As	Bi	Sn	Sb	Mn	Cu	Pb	Zn	Ni	Co	Cd	Fe%	Cr	Mo
	Mangani	80	1800	220	-0.5	yes	yes	5.8%	46	61	140	2	27	2	2.16	2	
a)	Linda	-0.05	42	1.48%	15	250	18	1.53%	1550	1.15	22.0%	54	54	130	14.5	6	
	Eloise	-0.05	17	130	2.0	400	24	3.3%	290	5.3%	5.5%	7	12	5	7.3	6	
	Merah Selasa	-0.05	47	450	1.0	90	-4	9800	700	1950	6.8%	9	14	25	4.51		
	Galanggang Black	0.70	25	260	?	10	16	4.15%	32	100	300						
	Reinier/Gorge/Gulley	0.04	60	4500	40	700	30	1.75%	1150	1.8%	7.4%	23	56	10	12.8	4	2
	Rambutan Atas		12	6.0	15			450	2.86%	6950	3.7%	32	55	130	22.4%	13	
	Rambutan Tinggi	0.05	432	130	350	70	8	1.14%	4940	4010	1.10%	38	115	41	32.1%	42	3
	Serassah	0.15	138	17%	?	530	115	840	5800	6.3%	5.4%						
b)	Brani	10.04	1036	390	?	-4	185	160	32	85	100						
	Sampil	3.34	66	430	-0.5	4	22	175	10	255	70	2	7	1	4.20	4	
	Rumput Pait	35.1	1050	870	0.05	6	185	1000	18	60	19	1	67	1	0.58	1	4
c)	Rambutan	2.9	124	350	-0.5			145	80	99	76	12	6	2	8.4	6	-1
	Silver	3.5	5438	260	-0.5			168	76	114	63	9	7	3	7.8	18	1
	Peter	-0.05	4	150	-0.5	-4	8	8500	25	28	93	4	24	1	5.5	4	
	Camp	?	150	1700	-0.5			205	45	52	37	4	12	1	7.8	4	
	Johanna	0.20	48	260	-0.5	-4	50	140	460	250	150	5	10	1	7.3	6	
	Woolrich	?	5	900	1.0	?		236	28	50	615	98	17	5	9.1	112	
	Egert II	0.1	30	400	-0.5	8	32	3.6%	530	1250	5800	17	17	4	0.2	2	
	Rumah Sakit	11.7	635	220	-0.5	-4	14	2.42%	118	295	115	24	32	1	6.1	15	2
	Rumah Potong Kiri.		59	2500	150			870	1640	615	7.95	30	30	450	5.80	5	
	Rumah Potong Kanan		68	9.0	0.5			4070	54	92	195	49	33	2	4.30	16	
	Helena		5	300	-0.5			610	24	39	108	38	24	2	5.4	11	
	East	0.05	-1	42		8	-4	710	36	42	75						

exceptions (e.g. Serassah). Gold only occurs in very small quantities in these veins, if it is detectable at all. These veins tend to contain higher Co than Ni contents, and the Co content in veins in this group is generally higher than in veins in other groups. Base metal sulphides occur in quite massive bands in some of these veins, though both in thin section and hand specimen, brecciation is common. The petrological differences between the different vein groups is not pronounced, the main difference consisting of the amount of sulphide material present, though veins in this group sometimes contain a much higher pyrrhotite content, which together with base metal sulphides may occur as a distinctive brecciated ore. Bi and Sn are present in the galena and sphalerite, rather than in separate minerals, and as these minerals are present in veins without Bi and Sn, different periods of sphalerite and galena mineralisation must have occurred in the Mangani area, unless the Bi and Sn were introduced metasomatically.

4.37.2 b)<u>Banded quartz veins with low base metal and Sb.</u>

The remaining veins can be divided into veins consisting mainly of banded quartz, and veins with irregular silicified zones and kaolin bands. It is quite possible that these vein types occur in the same mineralised zone, though the banded quartz indicates that a space was present to be filled, and some of the other veins consist of completely altered fault breccia. This suggests that the degree of extensional movement on fractures hosting these veins is the main difference. Veins in this category include the Rumput Pait, Sampil, Brani and Overtime Veins. The main outcrop of the Rambutan Vein may also fit best in this category, as a hard massive quartz reef is present, though it is not banded. These veins often contain disseminated pyrite and base metal sulphides, as well as rare thin (<3cm) veinlets of these materials, though the total base metal content is not as high as in the veins in the previous category. None of the new veins discovered during the present investigation contain high gold values, but generally veins in this category contain higher gold values than veins in the first category, the Rumput Pait Vein having been mined. In addition, the Brani and Rumput Pait Veins contain greater concentrations of Sb than many of the other veins, though the Serassah Vein contains similar amounts (115 ppm), and the Sampil Vein only contains a moderate amount (22 ppm). The Fe contents of these veins is much lower than in the other veins, as pyrite mainly occurs disseminated, rather than as veinlets.

4.37.3 c) Remaining Veins.

The other veins in the Mangani area, which do not easily fit in the first category, and do not consist of massive banded quartz reefs, have a number of common features, though there is no single feature characteristic of these veins, except the absence of bismuth. Many of these veins contain silicified zones, which sometimes grade into the vein type discussed in the last paragraph, but the silicified zones are much more irregular. Descriptions of the Rumput Pait Vein in De Haan et al. (1933) suggest that in the north, where the vein is hosted entirely in volcanics, this vein is similar to the other veins in group a, rather than consisting mainly of quartz like the veins in group b. Often the silicified zone consists of totally altered fault breccia, a feature also seen in group a, and even group b contains completely altered clasts around which some of the bands have grown. Veins in this group are often associated with kaolinised zones. Chemically the veins are also slightly different from the other veins in containing a higher Ni:Co ratio, though the Ni content is never very high (max 98 ppm). Cr is also most abundant in this group of veins (max 112 ppm), though the significance of the presence of this element is not fully understood.

4.37.4 The Mangani Vein

The Mangani Vein is the only vein in the Mangani area about which much is known, as it was extensively mined, though little new information could be obtained about this vein during the present investigation. The samples collected during the present study, as well as the descriptions in the literature suggest that the Mangani Vein does not fit into the categories just described, though if the other veins were examined in similar detail, other discrepancies may be discovered. De Haan et al. (1933) describe 5 major generations of ore in the Mangani Vein, while Kieft and Oen (1974) describe 2 main ore types. The earlier ores consist of an Mn-Ag-Sn paragenesis, and a later Ag-Au-Se paragenesis, with lower Mn, As and Sb than the earlier ore-types. Some of the different generations of vein material contain high base metal sulphide contents. The Bi content of the Mangani Vein has not previously been investigated, but Bi was not present in analyses of the limited number of samples collected during the present investigation, and was not seen as a constituent of galena when investigated under the microprobe.

4.38 Correlations between the different elements analysed

In the discussion of the different veins in the Mangani area, it has been pointed out that in some veins the element concentrations show a high degree of correlation. However, when the element correlations in different veins, or even in the same vein sampled at a different point are examined, few consistent correlations can be seen.

In some veins the Cd and Zn content is correlated, while in others it is not. Other elements for which a correlation is expected, e.g. Bi and Pb or Cr, Co and Ni similarly do not always show such a correlation. The correlation between Ag and Au and the other elements is particularly low, suggesting that the use of other elements as path finders is not applicable. Where a correlation between the precious metals, and another element occurs, either Mn or As are correlated with either Ag or Au, but rarely with both. In some cases Ag is correlated with Cu or Pb. Possibly calculation of the correlation coefficients between different elements might aid in identifying the elements most suitable for path finders for precious metal-bearing veins, but when the complexity of mineralisation in the Mangani Vein is considered, it is unlikely that any single element can be linked with the precious metals introduced at differing times in mineralising solutions with differing chemistry.

4.39 Reasons for the presence of the different vein types.

When the spatial distribution of the different vein groups outlined above is examined, it can be seen that veins with banded quartz all occur to the south of the Mangani Graben, hosted in Brani Conglomerate. This suggests that the host rock has affected the type of mineralisation present, unless the mineralisation formed before the Mangani Graben faults moved, in which case these veins may represent a type of mineralisation formed deeper in the earth. It is considered that the Brani Conglomerate may have acted more coherently, allowing space-filling vein material to form, while the chemical characteristics of the host rock restricted the deposition of base metal sulphides. The Rumput Pait Vein is located partly within the Mangani Graben (De Haan et al., 1933), and the lack of disruption of the mineralisation at the graben edge is thought to signify that the vein formed after the main phase of movement on the southern edge of the Mangani Graben.

The Bi-Sn bearing veins are all located to the north of the Mangani Graben, or near its northern edge. Many of these veins are also at a topographically much higher level. If the mineralisation formed before the Mangani Graben faults moved, then these veins may represent the higher temperature, deeper part of the veins seen in the graben. If the veins formed after the formation of the Mangani graben, then the much higher topographic location of these veins means that they may be the upper, nearer surface parts of veins similar to the gold bearing veins in the graben. This would suggest that gold bearing mineralisation is present deeper in these veins, a theory which can only be confirmed by drilling. Data presented by Malakov (1979) suggests that the bismuth content of galena increases with depth, which would suggest that if the Sn-Bi veins are associated with the other gold-bearing veins, then the gold-bearing part has already been eroded away. In addition Malakhov suggests that a high Sb:Bi ratio indicates a lower temperature of deposition, which would suggest that the veins in the northern part of the Mangani area formed at a higher temperature than those in the southern part. Similarly Boyle (1979) reports that commonly Tertiary veins are zoned, with Pb-Zn occurring at a lower level then the precious metals. However, no placer deposits are known in the Mangani area, suggesting that large amounts of gold-bearing material have not been eroded. Evidence suggesting that many of the veins in the Mangani area formed after the formation of the graben includes the common location of veins in fractures thought to have formed as a result of movement in the Mangani Graben. In addition the Linda-Eloise Vein system occurs in a fracture zone that has offset the edge of the Mangani Graben.

Some of the veins near the northern margin of the Mangani Graben, e.g. the Rumah Potong Kiri (Rainmaker) Vein show many chatacteristics of veins in this group, suggesting that the different groups are gradational. If the different groups are gradational, it is unlikely that the different vein types were deposited at different times, as a result of different mineralising fluids. The presence of small amounts of gold in the Galanggang Black Vein (located near the northern edge of the Mangani Graben, at a slightly lower topographic level) also suggests that the different vein groups grade into each other.

Another factor which may have caused the differences between these veins is the host rock. The Bi-Sn bearing veins occur in a part of Mangani where outcrops of Telisa Formation carbonaceous sediments are common, though none of the veins are hosted entirely in this lithology. De Haan et al. (1933) report that where the Rumput Pait Vein continues northward into this lithology, it becomes small, irregular and contains low precious metal contents. However, this lithology is also reported from parts of the Mangani Vein, and no adverse effects on the vein width and precious metal contents are reported. Malakhov (1979) also reports that the Bi content of mineral deposits is relatively unaffected by the nature of the host rock.

The difficulty in the classification of the Mangani Vein may be caused by the long depositional history (described in De Haan et al., 1933), so that the mineralisation is composite, with the differing periods of mineralisation having been formed at different depths as faulting affected the vein.

The present investigation has not resulted in the discovery of any significant difference between the veins that were mineable, and the other veins, except the gold content, though none of the veins with an appreciable bismuth content ever contain significant gold. The presence of a banded, massive quartz reef does not appear to be linked with good mineralisation, as in all cases the quartz reef is earlier than the sulphide and precious metal mineralisation. However, the possibility that gold may be very mobile in this environment would mean that barren vein outcrops at the surface give no indication of the value of the vein at depth. In addition, the altered zones at the margins of veins may contain higher precious metal contents than the actual quartz zone. Often only the harder quartz zone outcrops, therefore suggesting that sampling of outcropping material may give very little indication of the value of any mineralised zone.

4.40 Relationship of the hydrothermal alteration with the mineralisation.

A description of the general hydrothermal alteration affecting rocks in the Mangani region has already been presented in Chapter 2. Many other mineral deposits, including Ag-Au-Mn deposits which may be similar to mineralisation at Mangani (Sidorov et al., 1977) are associated with similar types of alteration, and in some cases a sequence of alteration zones is described. At Mangani the differing degrees of alteration could allow classification of the alteration types into categories related to zonal sequences described in the literature. Unfortunately the lack of outcrop in many parts of the area makes identification of a zonal arrangement of altered rocks difficult. It is also considered that there is probably not a coherent zoned pattern related to a single vein, or igneous body, but that the numerous faults have allowed penetration of the hydrothermal fluids in a chaotic fashion, with the degree of alteration of any rock related to its distance from a fault, and whether that fault was active during the entire alteration period. In addition any zoning is likely to have been disrupted by post-alteration faulting. For these reasons it is considered that the alteration type present in any one area gives no indication of the proximity to a mineral occurrence.

4.41 The relationship between the vein mineralisation and tuffisite dykes.

It has already been mentioned that many of the veins appear to be associated with tuffisite dykes. In other cases dykes associated with the mineralisation are so altered that their origin is difficult to determine. The gangue in many of the veins appears to have formed as a result of total alteration of the host rock, and for instance in the Reinier/Gorge/Gulley mineralised zone some of the gangue material consists of totally altered dyke material. This very common association of dykes and mineralisation suggests that there is some genetic connection. In addition the tuffisite dykes can often be distinguished from normal igneous dykes in the field by the high degree of alteration.

The origin of the tuffisite dykes has been discussed briefly in Chapter 2, where it was concluded that they formed as a result of brecciation of material, and transport of this material up fault zones by gas, or gas-rich fluids formed as a result of pressure release during periods of faulting. It is possible that the faulting itself was facilitated by the high pore-fluid pressure. The presence of feldspar megacrysts in many of these tuffisite dykes, including dykes intruded into sandstone, suggests that a cooling igneous melt was the origin for some of the material, with abruptly chilled fine grained fragments having been completely altered in many cases, and only the outlines of the feldspar grains still being visible. The presence of abundant fluid inclusions in vein material, and the evidence for boiling suggests that gas-rich fluids were also responsible for deposition of the mineralisation.

It is concluded that early in the mineralisation period the release of gas along fault zones resulted in the formation of the dykes, and later fluids were responsible for the transport and deposition of the mineralisation. This suggests that the presence of the tuffisite dykes may be used as an indicator of the presence of possible mineralisation.

4.42 Significance of the high manganese contents of many veins in the Mangani area

Many, though not all of the veins in the Mangani area contain several thousand ppm of manganese. A high Mn content is seen in many of the Tertiary gold and polymetallic deposits throughout the world. A similar association of precious metal, especially silver mineralisation with manganese, is reported from eastern Russian deposits by Sidorov et al. (1977), who conclude that such deposits are associated with volcanic belts in continental areas, but give no reason as to why the manganese should be present in Ag/Au deposits. The Tertiary Sumatran volcanic arc was built up on a core of Paleozoic continental rocks, suggesting that the Mangani deposit has a similar setting.

Boyle (1979) reports that Mn in its different oxidation states can be instrumental in both the solution and deposition of gold. The Mn(II) ion reduces soluble gold to the metal, while the Mn(IV) ion can oxidise gold, and make it mobile if complexing agents are present. Gold chloride complexes have been proposed as one of the ways in which gold can be transported, and manganese oxides aid in the formation of chlorine from HCl (the HCl having formed as a result of the reaction of H_2SO_4 with NaCl, and the sulphuric acid having formed from sulphides and water). For these reasons it is considered that the high manganese contents of these veins has been partly instrumental in the formation of the veins.

4.43 Origin of the gold and other minerals in the Mangani mineralisation

The association of the mineralisation with volcanics, and the presence of intrusive acidic rocks suggests that the metals in the Mangani mineralisation may be derived from magmas. However, Tilling et al. (1973) have suggested that though the range of gold contents in igneous rocks is small (0-12 ppb), the basic igneous rocks often contain larger amounts of this element than other rocks. The same writer also suggests that the gold content tends to be higher in the early crystallising minerals (mafic silicates, Fe-Ti oxides etc), so that gold is unlikely to be enriched in the residual silicate melt of a differentiating calc-alkali magma.

Alternatively, gold may be derived from leaching of the country rock, by circulating hydrothermal fluids heated by intrusive rocks. Weissberg et al. (1979) comment that metal rich (including gold) precipitates are being deposited from many of the active hot springs around the world, suggesting that even though the quantities of the metals in the waters are low, with sufficient time a viable deposit may be formed. At Mangani large areas show evidence of hydrothermal alteration, and the alteration appears to precede the mineralisation, suggesting that many of the minerals in the different veins may indeed have been derived from the surrounding rocks.

The presence of large amounts of manganese in veins from the Mangani area has already been pointed out, as has the possibility that the manganese was instrumental in mobilising and precipitating the gold. The source of the manganese is not certain. Volcanic rocks contain large amounts of manganese, but it is considered that the altered volcanics in the Mangani area have not been depleted in manganese. The presence of Mn epidote (piedmontite) even suggests that the volcanics have been enriched in this element. Stephenson et al. (1982) have noted that the Mangani area is anomalous for a number of elements including Ni, Co and Cr, and they have pointed out that such anomalies are associated with outcrops of serpentinites in other areas of Sumatra. Serpentinite lenses are often located along branches of the Sumatran

Fault System (SFS). At Mangani a boulder of peridotitic material was seen on the road, and a float sample of red chert was collected from the A. Rumah Sakit. This circumstantial evidence suggests that the Mangani area may contain such a lens of ophiolitic material, which may have been the source of the manganese. At Sungai Pagu, the association between the mineralisation and serpentinite is documented by Aernout (1914), suggesting that the high manganese contents of other Sumatran mineral occurrences may have been similarly caused by the presence of ultrabasic material along fault zones. As pointed out at the beginning of this section, basic and ultrabasic rocks also tend to have higher gold contents, though the volume of rock available to be leached is probably the most important factor, rather than the rock composition, assuming that a fluid of suitable composition is available to do the leaching.

Some of the other elements present in the different veins are also common in similar deposits from other areas. Boyle (1979) reports that minor amounts of tin are present in a number of gold deposits, and larger amounts are present in the Bolivian type tin-silver deposits. Selenium and tellurium, as well as thallium have been reported from the Mangani Vein by De Haan et al. (1933) in the form of crooksite ($(Cu,Ag,Tl)_2Se$), and unconfirmed altaite (PbTe). The present investigation has not found Bi in the Mangani Vein, but Brooks (1961) suggested that Bi and Tl showed a geochemical association. This would again suggest that the Bi bearing veins are linked in some way to the other veins in the Mangani area, and do not constitute a separate group of veins. Dzhandzgava (1979) also suggests that Bi, Te and Se concentrations in galena are directly correlated. However, Boyle (1979) has pointed out that Se and Te are rarely present in large amounts in the same vein. This conflicting data can only be summarised to say that general theories for the presence of such elements have not been extensively discussed in the literature, but the common associations of these elements in precious metal deposits suggests that they are there for the same reasons as the precious metals themselves.

At Mangani small outcrops of quartz and feldspar porphyry may be the upper parts of a larger granitic pluton, suggesting that some of the diverse elements may have been derived from the magma. Tin especially may have been introduced into the area, though this element too could have been derived from the large area of altered rocks.

In Sumatra pre-Tertiary gold concentrations are described from a number of areas (e.g. the Bulangsi area, Boomgaart 1941), and it is possible that at least some of the mineralisation is remobilised for earlier deposits, which may explain the large numbers of elements found in one mineralised area. The Guntung Volcanics are obviously younger than the main period of vein mineralisation in the Mangani area, as they contain blocks of vein material. This suggests that if re-mobilisation of earlier deposits did not occur, re-mobilisation probably occurred later, resulting in the formation of the base metal sulphide veinlets locally seen in these rocks. Even today, hot springs near Bonjol (12km to the east of Mangani) produce sulphurous, metalliferous precipitates, suggesting either that mineralisation is still in progress, or that re-mobilisation is still occurring. The general geological environment at Mangani is similar to that seen in many areas of stratiform, syngenetic base metal mineralisation. No good evidence has been found for the presence of such mineralisation, but it is possible that the high base metal content of the northern veins has been derived by re-mobilisation of such mineralisation up fault zones.

4.44 General conclusions about the mode of formation of the Mangani Mineralisation.

The different veins in the Mangani area are considered to be epithermal veins formed in an active fault zone, with much of the vein material being derived from hydrothermal leaching, and precipitated in the fault zones as a result of the lower pressures and temperatures in those zones. In many of the veins the gangue has not formed from remobilised material, but as a result of total alteration of fault gouge. In some cases mineralisation was preceded by deposition of tuffisite dykes resulting from gas escaping up fault zones, and carrying components of a partially solidified magma body, as well as clasts from the country rock.

Three different groups of veins have been identified in the Mangani area. The differences between the groups are considered to have been partly caused by the differing lithologies in the area, and partly as a result of vertical zonation. Veins consisting mainly of banded quartz with a low sulphide content occur to the south of the Mangani Graben, hosted mainly in the Brani Conglomerate. Sn-Bi bearing veins with a high base metal content occur in the northern part of the area, mainly to the north of the Mangani Graben. These veins are often partly hosted in carbonaceous Telisa Formation mudstones. Veins with moderate base metal contents, but little Sn or Bi are often associated with kaolin bands, and are hosted in volcanics in the Mangani Graben.

Some of these differences are thought to be caused by vertical zonation, but it is not known whether different portions of the veins are exposed as a result of post-mineralisation faulting, or as a result of their different topographic heights. Vertical faulting is considered to have little effect upon veins crossing the southern margin of the Mangani Graben, where the differences are considered to be mainly caused by the host rock lithology. There is a possibility that the veins to the north of the Mangani Graben are gold bearing at depth, though evidence is present both for and against this theory.

Most of the metals in the veins are thought to have originated from the volcanic pile, but there is also a possibility that some metals have been derived from underlying differentiating magmas, and even from previous deposits. Such a multistage origin of the metals may explain the large numbers of elements present, and the absence of some of the typical metal associations (e.g. tin, but no tungsten, is present).

Though the evidence is circumstantial, it is possible that the high manganese content of the mineralisation in this area has been derived from ophiolitic material caught up along fault zones. The manganese is considered to have been instrumental in both mobilising the precious metals from the volcanic pile, and in precipitating the mineralisation.

Chapter 5

Detailed investigation of mineralisation at Mangani.

Further investigation of some of the mineralised areas of Mangani using geophysical techniques and soil sampling, commenced during a visit to Mangani in June-September 1981, with the help of a team from the Indonesian Geological Survey, Department of Mineral Resources. The work was completed during March-April 1982, with logistic support provided by CSR Ltd.

5.1.1 Reasons for investigating the Bukit Bulat area.

Geological mapping in the earlier stages of the project had shown that there were many more veins in the Mangani region than had previously been thought. Geochemical investigation had shown that several areas had anomalous abundances of a number of elements. The Bukit Bulat area (Fig. 5) was chosen for further study using geophysical methods for the following reasons.

a/ Stream and soil samples from the area were anomalous for several elements, most notably lead and zinc, but some samples also contained gold or silver.

b/ A number of vein outcrops had been found in the two branches of the Gallanggang River, on either side of Bukit Bulat (Fig 5). Large blocks (1m by 0.5m) of manganese dioxide, as well as large blocks of rhodochrosite, were found in the western branch of the A. Gallanggang. The Mangani Vein is noted for its high manganese content, so there is also a distinct possibility that the Mangani Vein may extend into this area.

c/ There had never been any mining activity in the Bukit Bulat region so geochemical anomalies could not be caused by contamination. The rivers had never been channelled for hydroelectric power. In other parts of Mangani there are large buried cast iron pipes whose location was not exactly known. Such pipes cause geophysical anomalies, especially using the VLF-EM method. Maps of the mine area (Figure 18) did show houses near the junction of Gallanggang Kanan and Kiri, but these are outside the area investigated.

d/ No previous geophysical work had been done in the Bukit Bulat area, while some work had previously been done in the southern part of the Mangani area by the Indonesian Geological Survey (Harsono et al. 1978).

Another consideration was the amount of geological information which might be gained from geophysical investigation. Outcrop in the Mangani area is scarce, and any elucidation of geology or structure would be welcome.

5.1.3 Reasons for investigating the Rambutan-Silver Vein area.

As well as the work in the Bukit Bulat area, it was considered that some work over the Rambutan and Silver Vein region would be valuable (Fig. 5). This small area was near to the camp used during the survey, and is known to contain at least 2 veins. It was hoped that this work would indicate the type of geophysical response to be expected from quartz veins with only small amounts of sulphides. The southern edge of the Mangani Graben also lies within this area.

5.1.4 Survey procedures

Most veins in the Mangani region are oriented NNE/SSW, so it was decided to cut lines through the jungle, oriented approximately E/W in order to intersect these features at a high angle. The ridge along Bukit Bulat trends approximately 170^{o}, so the base line there was cut in this orientation to allow easier access and smaller terrain corrections.

A point in the centre of the base line became the grid position 0E 0N, and all grid positions were numbered with the number of metres away from this point.

14 cross lines oriented 080^{o} were cut at 80 to 100m intervals. Using these spacings and orientations it proved possible to avoid the worst of the vertical terrain, though near the graben edge sections of the Gallanggang River still proved impossible to cross. Most of these cross lines extend 500m east and west of the base line, so that in total more than 15km of lines with over 700 stations were cut in the Bukit Bulat area.

On all grid lines a station spacing of 20m was used for geophysical data, and soil samples from the upper part of the C soil horizon were collected at 40m intervals. Figure 5 shows the location of all grid lines. In the following text, locations on the Bukit Bulat grid are referred to by line number, eg line 500N (500m north of point 0,0), and station number east or west (eg 500N,500E).

Unfortunately in the Rambutan Silver Vein area, the Rambutan and Galanggang Rivers are deeply incised and in many places the valley sides are vertical. Here two lines 50m apart, oriented 050^{o}, just avoided these problems. These lines are marked on Figures 4 and 5, and are labelled as lines A and B, with station numbers 1A and 1B at the western ends.

Some lines were cut by a surveyor using a theodolite. Others were cut using a tape and compass to measure orientation and distance. Enclosure 1 and Figure 4 are the topographic maps produced by P. Bangiel Eragie (surveyor). Generally the tape and compass method was reasonably accurate, as cross lines which were also cut using a tape and compass came out at the right grid position. In particularly steep areas the station spacing was sometimes not so accurate. Line orientation suffered in areas with large fallen trees, as it was difficult to clear a route far enough, so that a long line of sight could be obtained. On all lines the slope between stations was measured with a clinometer, and a sketch of the topography was made. This information was used to construct topographic profiles, which are shown in many of the geophysical maps. All topographic profiles have the same horizontal as vertical scale.

Part A Detailed soil geochemistry

5.2.1 Introduction.

In the Bukit Bulat area 357 soil samples were collected at 40m intervals on the lines decribed above. Soil sampling procedure was identical to that described in Chapter 3. All samples collected in the Bukit Bulat area were analysed by CSR Ltd for 5 elements (Ag, As, Pb, Cu, Zn). The details of the analytical methods are not known.

No samples were collected from the Rambutan-Silver Vein area as pieces of ore and metal were scattered throughout this area, and it was felt that the contamination would obscure the geochemical response of the mineralisation.

When the samples were collected a note was taken of the depth the sample was collected from and the colour. These details are shown in Figure 78. Large areas have a similar soil colour, and a number of samples near known mineralised areas (e.g the Eloise and Merah Selasa Veins) have a black colour, which may be due to the high manganese content.

5.2.2 General discussion of analytical results

Figure 79 shows the analytical results for soil samples from the Bukit Bulat area plotted as profiles. In addition the topographic profile for each line is marked. Figures 80 to 84 are contour plots for each element.

On Figure 79, details of the different mineralised areas can probably be seen more clearly than on the contour plots, as some samples are anomalous for one element, while other samples are anomalous for other elements. A number of smaller anomalies near the base of slopes may be hydromorphic anomalies, but a number of very large anomalies (e.g. with lead contents over 6000 ppm) are probably related to mineralisation.

Almost all of the southern part of the area has higher element abundances than the northern part, with copper over 20ppm, lead and zinc over 100ppm, manganese over 1000ppm, and arsenic over 10 ppm. The reason for this distribution is not known, but one possibility is that a layer of tuff was deposited after the regional hydrothermal alteration, and the low element content on the higher ground is a result of blanketing by such a layer. Alternatively mineralisation decreases northward away from the edge of the Mangani Graben, and also decreases to the east and west away from the Bukit Bukat fault bounded block.

5.2.3 Analytical results plotted as profiles.

On Figure 79 a N/S line of peaks occurs in the Galanggang Kanan valley, and is probably related to the Linda-Eloise Vein system. It is not entirely certain whether the Merah Selasa Vein is the southern continuation of this zone, as this vein dips at a very shallow angle, and may be outcropping all along the hillslope. On the aerial photograph of the area (Plate 12) a N/S lineament can be see to the west of the Merah Selasa Vein, and may be caused by the southern continuation of the Linda-Eloise Vein system, in which case the anomaly at 600S,160E is caused by a separate vein. Geological mapping has shown the the Linda-Eloise Vein system is located partly within a N/S fault, though in some cases the vein appears to be cut by a later N/S fault.

Another line of peaks can be related to the northern margin of the Mangani Graben, element values being of a similar magnitude to those over the Linda-Eloise Vein system. No mineralisation related to this zone is exposed, suggesting that this a previously unknown mineral occurrence.

Some of the largest anomalies occur on the western flanks of Bukit Bulat, on lines 80S to 80N. Again these are not related to known mineralisation.

Anomalies related to the Reinier-Gulley-Gorge Vein systems are small, though the presence of a gorge in this area limited sampling. To the south of the exposed part of this zone a very large anomaly occurs at the western end of line 240S. This may be caused by the southern continuation of this zone, or by the northern edge of the Mangani Graben. The lineaments on the aerial photograph (Plate 12) suggest that the edge of the Mangani Graben has been displaced by N/S faults, so either of these interpretations may be valid.

5.2.4 Analytical results plotted as contour maps.

Contour maps give a visually better indication of the location of anomalous areas, though the preconceptions of the person drawing the contours can result in the enhancement of trends in one particular orientation, while trends in an orientaion which was not expected may be obscured.

a/ Lead Anomalies.

Figure 80 shows the distribution of lead. Some samples over the Linda-Eloise Vein system contain over 1000 ppm lead, but generally the samples with most lead occur on the western flanks of Bukit Bulat. It is not known whether the wide spread of the anomalous zone at the eastern end of lines 80S to 240S is caused by the vein dipping at about 40-55^{o} at a similar angle to the hillslope, or whether an apparent NE/SW line of anomalies joins with the N/S line at this point. Hillslopes in this area are steep, and it is also possible that some of the large anomalous areas are caused by soil creep.

A very large anomalous area is located on the western flanks of Bukit Bulat, and contains the largest lead values (6650 ppm). The cause of this anomalous area is unknown.

Three of the lines cutting the northern margin of the Mangani Graben have lead contents over 1000 ppm, suggesting that this zone is enriched in lead. Unfortunately the orientation of the lines cut in the Bukit Bulat area is not ideal for delination of mineralisation with this orientation, but when the survey was planned there was no indication of mineralisation with this orientation. It is still possible that each of the high values ascribed to mineralisation along the edge of the Mangani Graben are in fact caused by N/S mineralisation cutting the edge of the graben at these points, but this would be rather fortuitous.

One isolated anomalous area occurs at the very eastern end of line 600S. This may possibly be caused by the eastward extension of the mineralised zone along the Mangani Graben edge, though the aerial photograph lineaments suggest that the graben edge is displaced northward by the N/S faults.

b/ Zinc anomalies.

In the same way as the lead abundance map, the concentration of high values in the southern, central part of the area is very noticeable.

The N/S anomalous zone associated with the Linda-Eloise Vein system is well defined, suggesting that this mineralisation is enriched in zinc. This agrees with the analytical results from specimens from these veins. This anomalous zone also appears not to join up with the Merah Selasa Vein, unless as previously discussed, this vein is dipping parallel to the hillslope.

The samples collected from the aproximate location of the northern edge of the Mangani Graben do not seem to be especially enriched in Zn, except at the western end.

The area which was particularly anomalous for lead on the western flanks of Bukit Bulat only seems enriched in zinc near the hill ridge, near the point at which anomalous samples were collected during the initial soil survey. One possibility is that this is part of a NW/SE trending zone, connecting up with the anomalous samples at 500S, 140E.

c/ Manganese anomalies.

A N/S anomalous zone connected with the Linda-Eloise Vein system is clearly present as far as line 240S, but does not appear to continue further.

An anomalous zone related to the Mangani Graben edge still appears to be present, though the highest values are only present at the western and eastern ends.

The NW/SE trending anomalous zone wich appeared to be present in maps of the other elements again is visible.

D/ Copper anomalies.

The Cu content of these soil samples is much lower than the concentration of the other base metals present, the maximum value being only 300 ppm. Samples analysed from veins in this area also contain only a small amount of copper, suggesting that if the Mangani gold veins are related to a porphyry copper deposit, then this is still very deeply buried.

The highest copper content occurs in soils over the

Merah Selasa Vein. The exact dip of the Merah Selasa Vein is not known, but if the vein dips at a shallower angle than the hillslope, the area anomalous for Pb, Zn and Mn approximately 50m further west may also be related to this vein. However copper contents in the second area are low, suggesting that the anomalies are more likely to be caused by a separate mineral occurence.

Soils along the graben edge show some copper enhancement (60 ppm).

The anomalous sample (200 ppm) near the eastern end of line 160S appears to occur further to the west than other anomalous samples thought to be related to the Linda-Eloise Vein system. The reason for this is not known.

One sample from the anomalous zone on the western flanks of Bukit Bulat contains a high Cu content (200 ppm), but this may partly be due to the scavenging effect of manganese, which is also abundant in this sample.

E/ Arsenic anomalies.

The distribution of anomalous arsenic samples is more patchy than that of other elements. Most samples contain less than 10 ppm As, but some samples contain as much as 150 ppm As.

The northern part of the Linda-Eloise Vein system appears to be related to higher soil arsenic levels, but the large anomaly (100 ppm) to the west of this zone has no known origin, and this area is not particularly anomalous for any other element.

Another area with no associated anomaly for the other elements analysed, but with 100 ppm As occurs to the west of A. Galanggang Kiri, on line 240N. The reason for the high As content is unknown.

In the Merah Selasa Vein area soil samples are moderately anomalous (30 ppm).

The area most conspicuously anomalous for arsenic occurs at the western end of lines 240-400S. This zone may partly be caused by mineralisation along the graben edge, but there also seems to be a N/S anomalous zone, possibly related to the Reinier-Gorge-Gulley mineralised zone. However these samples are not anomalous for other elements.

F/ Silver anomalies.

No contour map of the silver contents of soils in the Bulat area has been made, as most samples contained no silver, and 2 ppm Ag was the maximum measured. This is slightly surprising, as a number of stream and soil samples from this area analysed during the initial survey (described in Chapter 3) did contain some silver. The initial analytical work was done both at Chelsea College, and by the Indonesian Geological Survey, while later samples were analysed by CSR Ltd. The method of analysis is not known, so possibly care was not taken to avoid precipitation of the silver with halides. However most of the vein material from this area analysed also contained very little precious metal, suggesting that the analytical results are valid. As already discussed, mineralisation in this area is chemically different from the precious metal-bearing veins in the graben area.

5.3 Geochemical conclusions.

All the elements analysed, except silver, provided some useful information about the mineralisation in the area. The geochemical response over the Linda-Eloise Vein system is of a similar magnitude to that occurring in areas with no known mineralisation, suggesting that concealed mineralisation may be present. The zone on the western flanks of Bukit Bulat, and the zone along the northern edge of the graben in some cases contain higher values of elements than over the known mineralised zones, suggesting that these areas should be examined further using geophysics. The Reinier-Gorge-Gulley Vein mineralised zone does not have an associated large, or continuous anomalous zone, suggesting that if this is the northward continuation of the Mangani Vein, it is not of great significance.

The copper analyses were perhaps the least useful, as most of the anomalous areas were also anomalous for other elements. Generally the different elements were most abundant in different areas, possibly indicating that different types of mineralisation are present.

Lead, zinc and manganese locally occur in very substantial amounts (thousands of ppm), suggesting that significant concentrations of sphalerite and galena are present in these areas.

The conclusions about the location of mineralisation are discussed after the section on the geophysical work done in this area.

One feature of this soil survey which may be particularly useful for a low budget exploration survey is the correspondence between soil colour and the presence of geochemical anomalies. Black samples are always highly anomalous, possibly the dark colour being caused by a high manganese content, which in one sample at the western end of line 240S exceeded 1%. Brown coloured samples tend to occur in the area of generally elevated element content, while yellow samples occur in areas with low element contents. The significance of some of the red coloured samples is not clear, but many again appear to be associated with mineralisation.

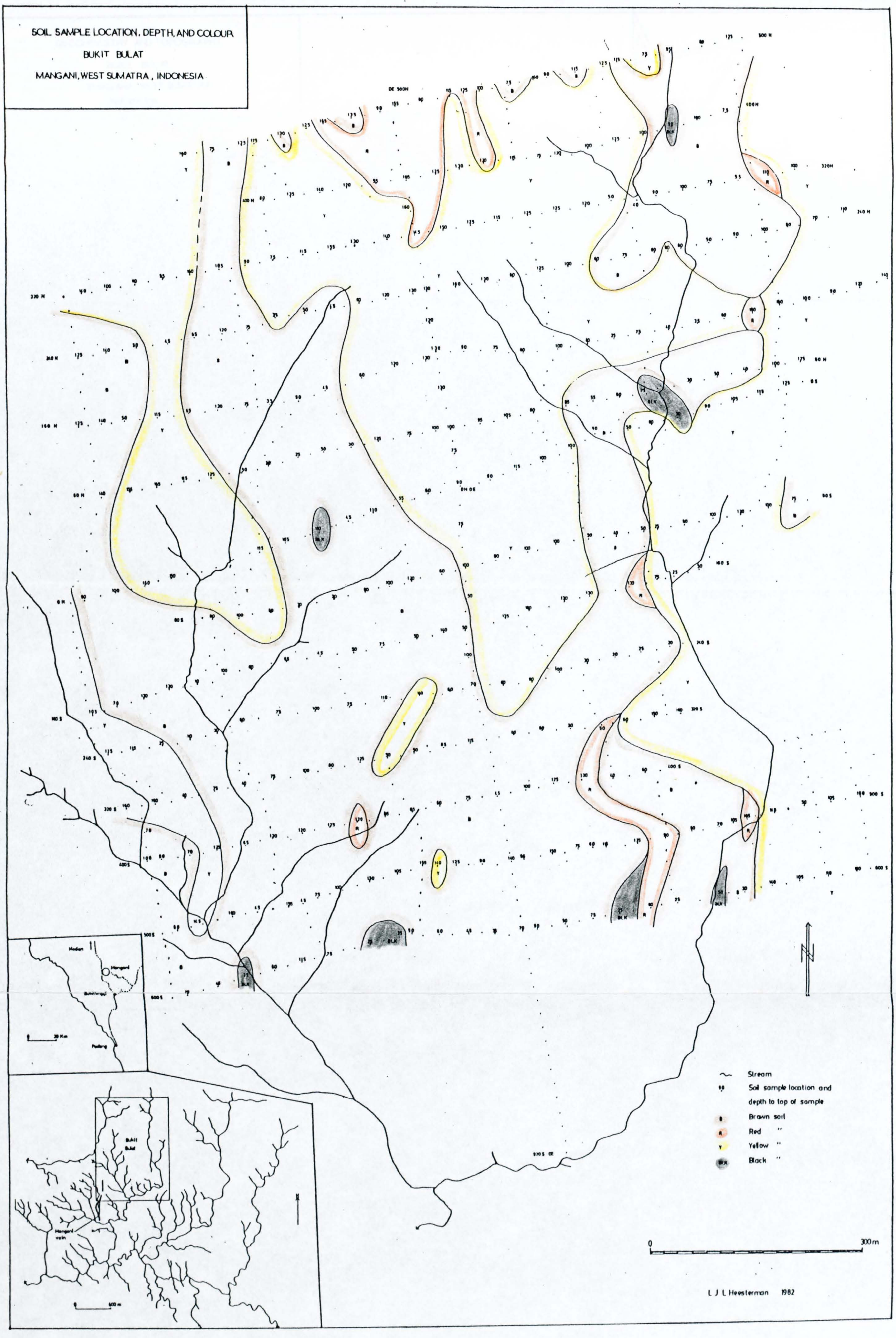
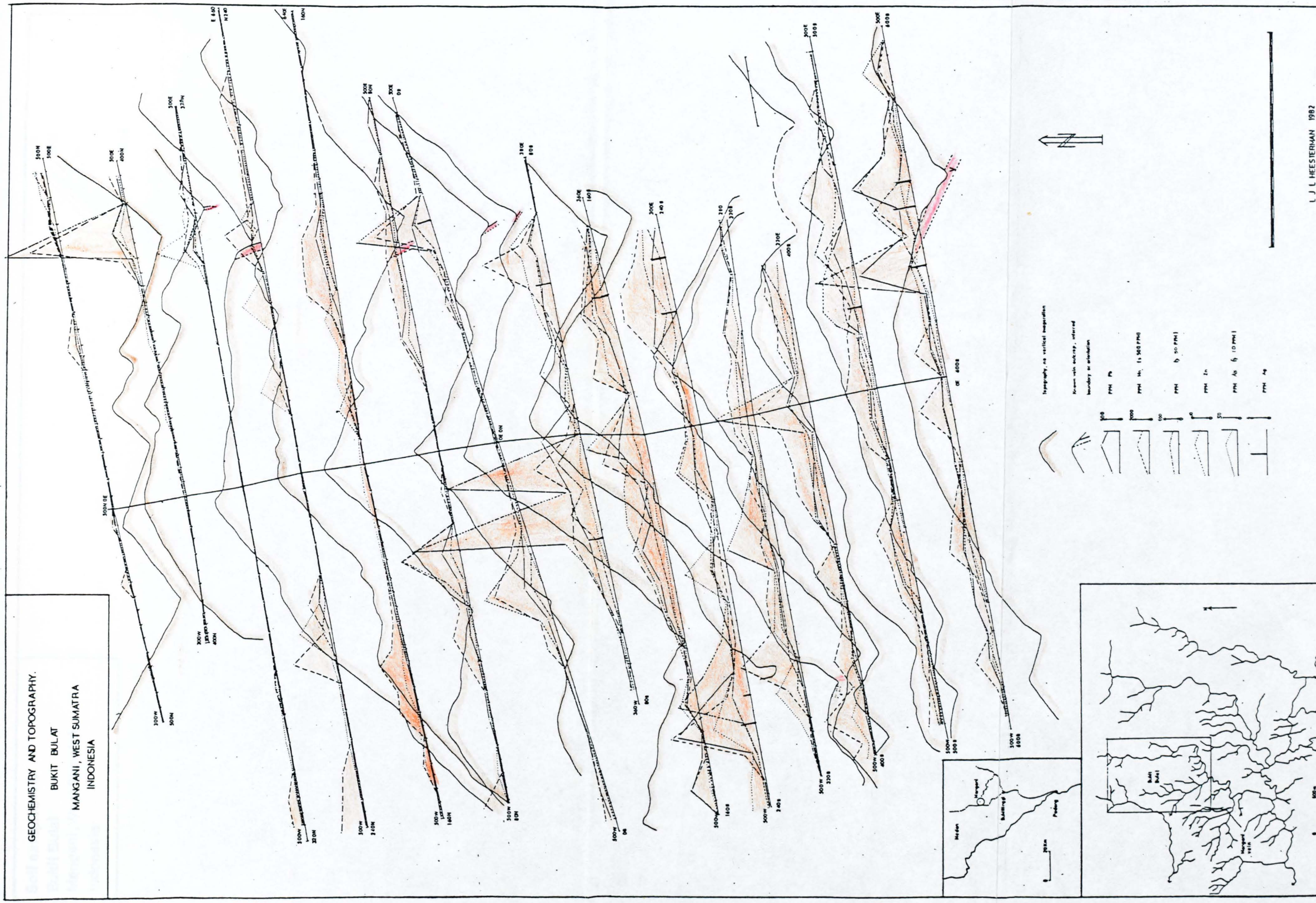


Figure 78. Soil sample location, depth and colour in the Bukit Bulat area.

Figure 79. Analytical results and topographic profiles in the Bukit Bulat area.



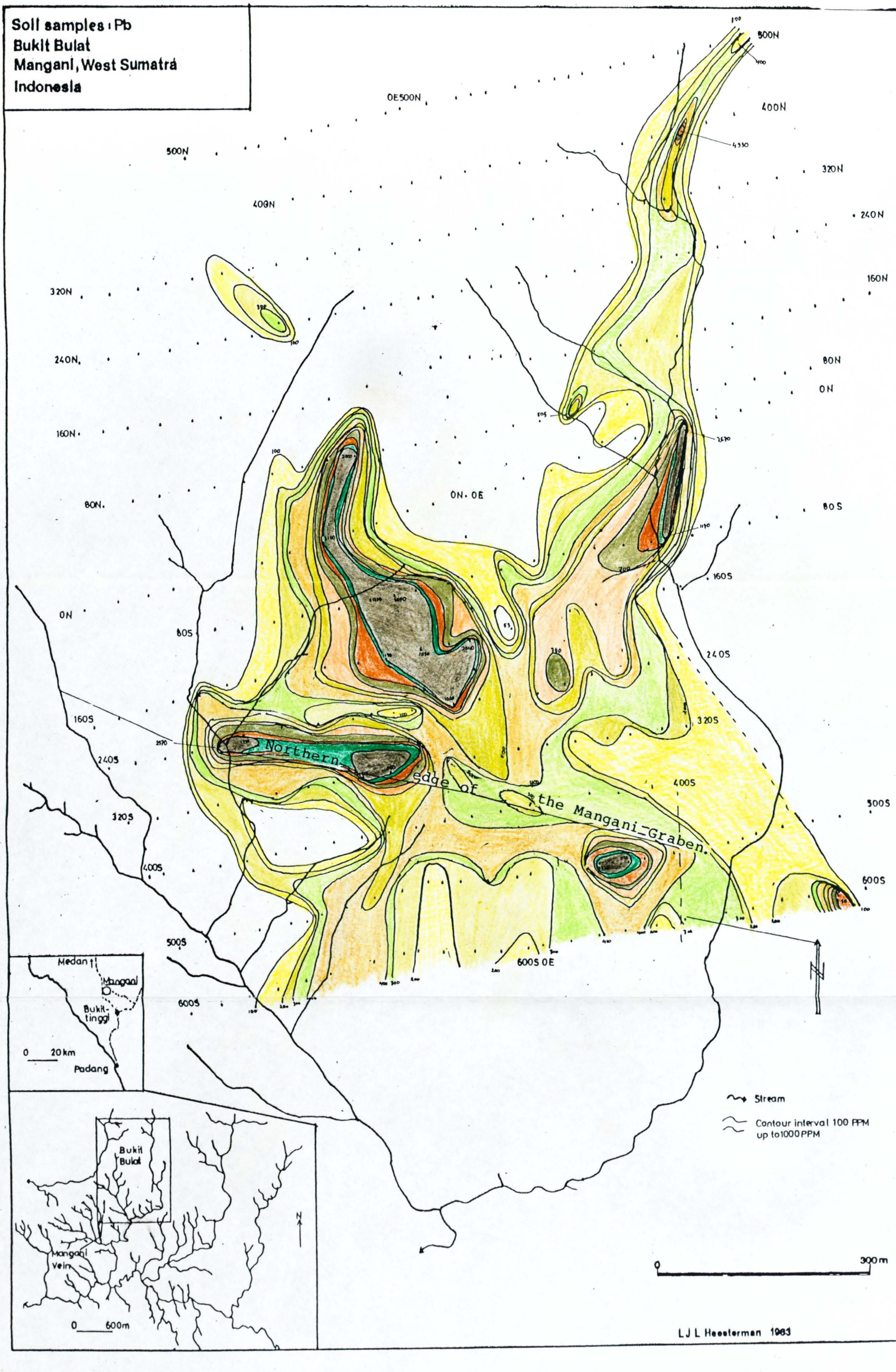


Figure 80. Pb content of soil amples from the Bukit Bulat area.

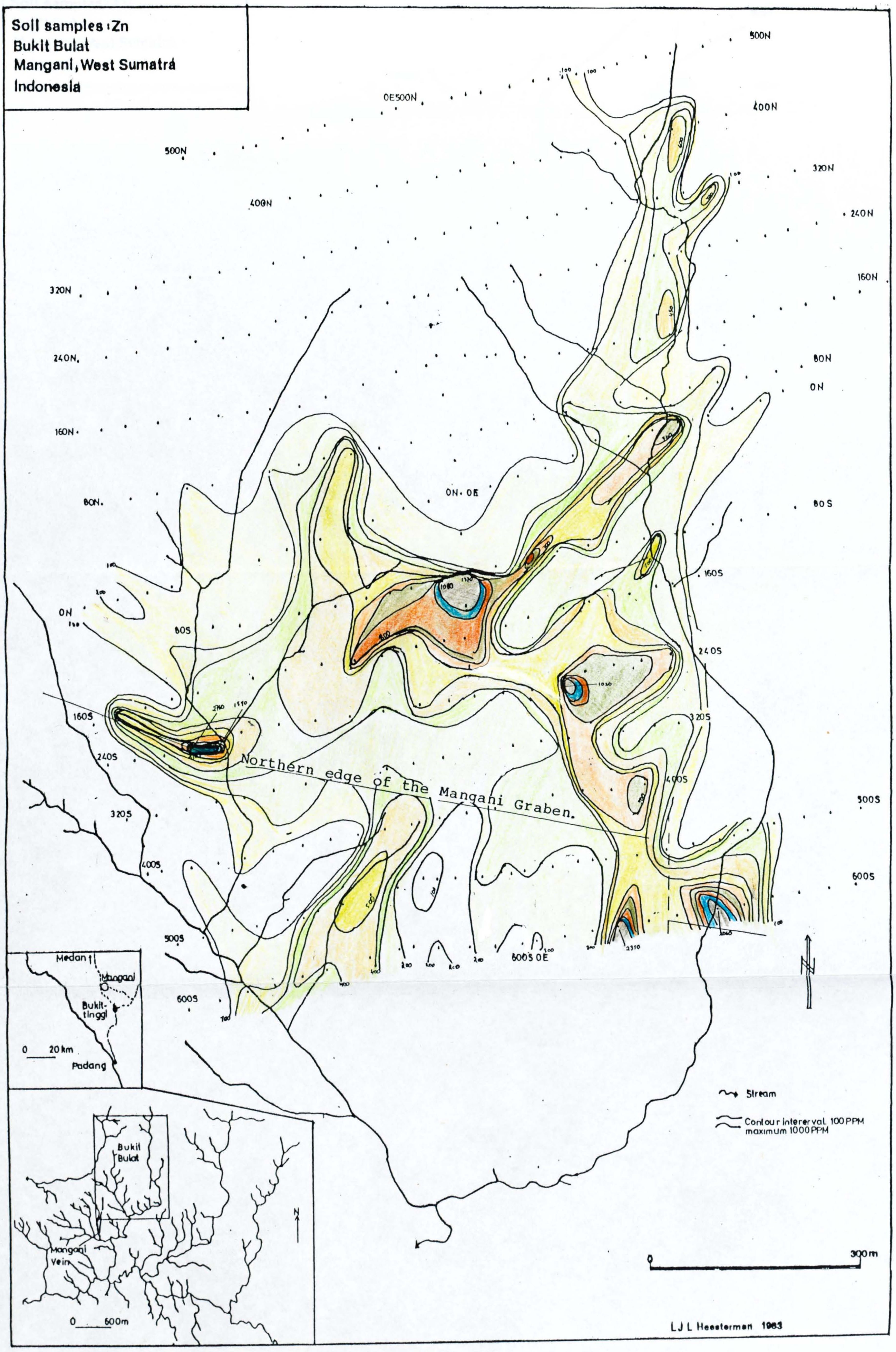


Figure 81. Zn content of soil samples from the Bukit Bulat area.

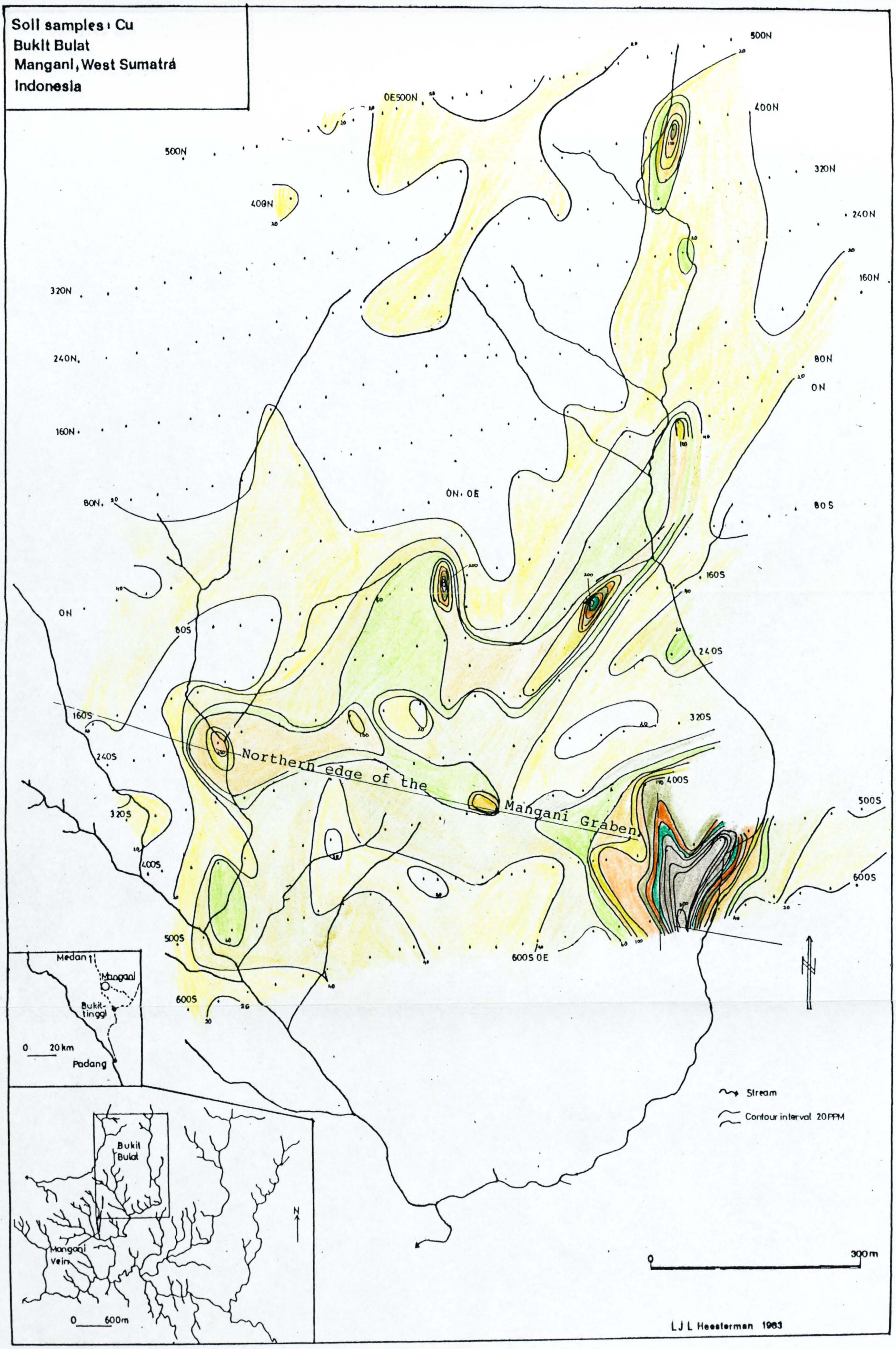


Figure 82. Cu content of soil samples from the Bukit Bulat area.

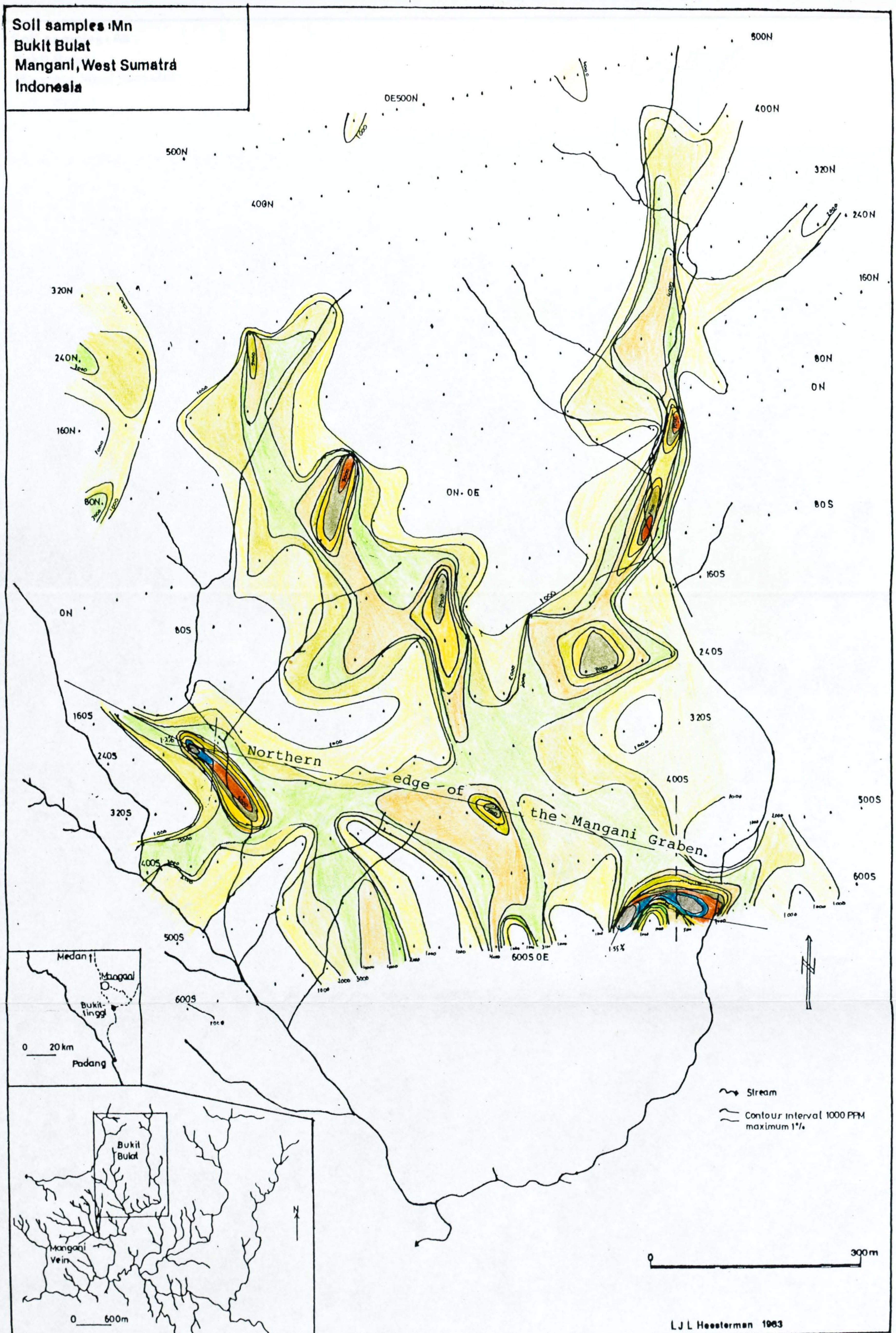


Figure 83. Mn content of soil samples from the Bukit Bulat area.

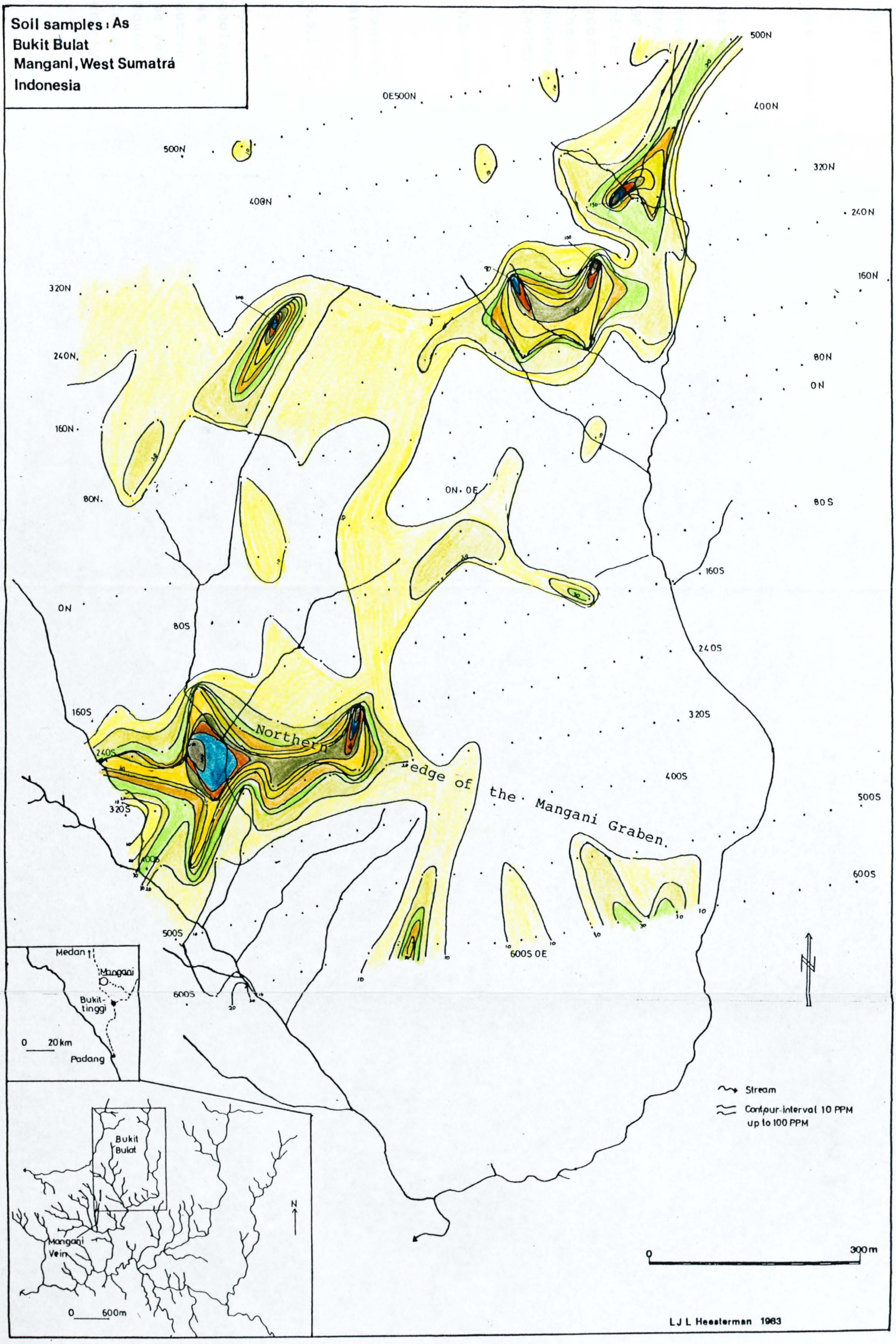


Figure 84. As content of soil samples from the Bukit Bulat area.

Part B Geophysical work

5.4 Previous geophysical work in the Mangani area.

The previous geochemical work done in the Mangani area has been discussed in Chapter 3.

The southern half of the Mangani area was investigated by the exploration geophysics section of the Indonesian Geological Survey (Harsono et al., 1978) using SP and magnetics (vertical and total field). About half of this area had previously been investigated using soil geochemistry (Machali et al, 1976). The area covered by their work is shown in Figure 16. The results of the geochemical and geophysical work done by the Indonesian Geological Survey are summarised in Figure 17.

5.5 The geophysical response of mineralisation, host rock and overburden.

In planning the geophysical work at Mangani it was considered that there might be three main types of mineralisation.

5.5.1 Vein mineralisation.

15 mineralised quartz veins had been discovered at Mangani before the present study started. Detailed geological mapping showed that there were at least twice as many veins. Four of these newly discovered veins outcrop in the Bukit Bulat area. and there were likely to be veins that were not exposed along streams. The veins found at Mangani vary dramatically in type, and the following types of veins would provide very different geophysical targets.

a/ Some veins consist mainly of quartz with a small amount of finely divided sulphides, free gold and minor manganese. The southern part of the Rumput Pait Vein is an example of this type.

This vein was mined so some information is available about its characteristics (Chapter 4). The actual ore zone varies in width, generally being 2-3m wide. Parallel barren quartz veins increase the total width of the vein complex up to 10m. In the south the vein is truncated by a fault, and in the north the vein dies out. The vein was mined for a length of 250m along strike. Frequent cross faults divide the vein into short segments. The Rumput Pait Vein is unusual in that it dips at a very shallow angle near the surface (less than 45^{o}). The host rock is strongly altered and silicified adjacent to the vein, so that the boundary becomes gradational.

This type of vein is almost undetectable by any method. The density of the vein is similar to that of the host rock, so gravitational methods will be ineffective. Magnetic methods will also be ineffective as there is no magnetic contrast between the vein and host rock, though a small magnetic anomaly occurs over the probable northern extension of the Rambutan Vein (Harsono et al., 1978). This vein, like many other veins at Mangani, has an associated feldspar porphyry dyke, which may be the cause of the anomaly. Electrical and electromagnetic (EM) methods require mineralisation to act as a fairly continuous conductor in order to be effective. High frequency EM methods such as VLF might detect these veins, but the response would be indistinguishable from that produced by faults. Methods such as IP which respond to disseminated mineralisation would detect these veins only if the host rock in those areas was not altered and pyritised. Even using soil geochemistry it would be difficult to discover such veins as the only anomalous element is gold, which would only be seen if the sample was taken directly over the vein, or from soil derived from the vein.

The conclusion that can be drawn from this is that such veins can only be discovered in outcrop, and it is necessary to verify their extension by trenching and drilling.

b/ The Mangani Vein is an example of a composite vein with bands of mechanically brecciated massive sulphides alternating with quartz bands. This was the main vein mined at Mangani, and quite a lot is known about it. Two sections of the vein were mined for a combined length of 560m (De Haan et al., 1933; M.M Aequator annual reports). This vein complex consists of at least 3 separate quartz veins, some with associated mineralisation. The earlier veins bend and the later veins cut across that bend. This means that the vein complex can not be compared easily with a simple sheet conductor. The overall dip of the Mangani Vein is 60-70^{o}E, and it varies in width up to 10m in places, though on average the workable part is less than 2m. The host rock on the hangingwall side has been completely altered to a kaolin band, up to 1m wide. Beyond the kaolin band the host rock is extensively altered for several metres. Like all other veins, cross faulting with displacement up to 10m is common.

Such veins, especially in their wider parts, would be detected by methods such as Ionisation Potential (IP) and Self Potential (SP), which respond to discontinuous conductors. Ground water containing dissolved minerals would allow the veins to act as conductors, despite brecciation and faulting. For this reason electrical methods such as resistivity and self potential, and electromagnetic methods would all be capable of detecting veins with high sulphide content. Gravitational methods would still be inapplicable as the size of the body is relatively small.

The Mangani Vein contains little magnetic material, but a number of the veins in the northern part of the Mangani area, including those in the Bukit Bulat area contain pyrrhotite, and might well be detectable with magnetics. The Linda Vein is an example of such a vein. This vein is unusual in that it has a wide zone (10m) of tectonically granulated sulphide and minor quartz, as well as thin (15cm) bands of massive sphalerite and galena. Such veins should make excellent conductors and give a good geophysical and geochemical response.

c/ Geological mapping has shown that some of the mineralisation consists of highly mineralised fault zones, so that clasts of massive sulphides are surrounded by quartz, kaolin and host rock debris. These veins would not be good conductors. IP and SP should be able to detect zones of discontinuous mineralization, though the pyritized nature of the host rock would mask the geophysical response of such veins.

In one case an unmineralised fault zone contains clasts of sulphides mechanically incorporated in the fault breccia. Such zones may have a similar response to the more mineralised zones.

All of the veins in the Mangani area seem to have formed along active fault zones, suggesting that every gradation exists between the different mineralisation styles mentioned.

5.5.2 Disseminated sulphides.

Mapping had shown that large areas of Mangani had been extensively altered, with feldspars changing to epidote and clay minerals, and with disseminated sulphides and veinlets of sulphide permeating the rock. Most of the sulphide consists of pyrite, though in some places chalcopyrite and arsenopyrite occur. Some of the veinlets also contain galena.

Investigation of these broad mineralised areas was considered useful for two main reasons. First of all these regions might be large enough, and contain enough base metals or gold and silver, to be regarded as valuable in their own right. Bougainville in Papua New Guinea was first investigated as a gold deposit, but was mined as a porphyry copper deposit. Porphyry copper style mineralisation can have gold-bearing quartz veins at a higher level. Secondly, it is possible that disseminated and vein mineralisation are the result of the same process, so regions of disseminated mineralization might also be areas that contain veins. Hydrothermal vein mineralisation can be surrounded by pervasive host rock alteration. Disseminated mineralisation is best detected by IP, though some SP response would also be expected.

Other geophysical methods would not detect regions of disseminated mineralisation, as there is no gravitational or magnetic contrast, and the zone is not a continuous conductor.

5.5.3 Stratiform volcanogenic mineralisation.

Mineralogical and chemical investigation of mineral samples from the Bukit Bulat area (Chapter 4) has shown that some of these are different from the samples found further to the south. One possibility for this difference is that the Bukit Bulat Veins have formed as a result of reworking of earlier mineralisation. The geological environment at Mangani is similar to that encountered in many areas of stratiform volcanogenic mineralisation, and some of the large areas of moderately high geochemical anomalies may be caused by such mineralisation.

IP is a suitable method of detecting large areas of mineralization, and SP anomalies would also be considerable. In this case gravity anomalies might also be considerable as a result of the higher density of a large volume of rock. Magnetic methods would also be useful as the presence of magnetic pyrrhotite common in such deposits should provide a good contrast with non magnetic sediments and tuffs.

5.5.4 Host rock geology.

The geophysical methods chosen should also provide information on the host rock geology and structure. Magnetics would be useful in separating basic rocks (Amas Volcanics), from sediments (Telisa and Sihapas Formations). Electromagnetic methods, especially VLF, will pick up faults if they are associated with a conductivity contrast. Gravity anomalies are best produced by large simple structures, such as a large body of higher density (e.g. gabbro) in lower density host rock (sediments). The Mangani geology and structure is probably too complex for elucidation by gravity modelling, and collecting gravity data is one of the most time consuming of the geophysical methods.

5.5.5 Lateritic soils

Lateritic soil is one of the biggest problems of geophysical surveys in tropical areas. Lateritic soils are conducting, especially when wet, so the varying soil thickness can produce anomalies with electric and electromagnetic methods. If soils are thick, the depth of penetration of high frequency electromagnetic methods is limited. For any electrically based method this means the signal to noise ratio is greatly reduced.

As already mentioned in Chapter 3, soils in the Mangani area are generally not very thick, so that it was considered that lateritic soils would not be a problem.

5.5.6 Topographic effects.

Mangani lies in the Barisan Mountains, and Bukit Bulat is one of the higher, steeper parts of Mangani. Most geophysical methods are affected by topography, and some methods, such as gravity, require extremely accurate topographic maps in order to make a sensible interpretation. For some methods a qualitative interpretation can be made if the approximate topography is known. SP data can be interpreted if the approximate angle between any sheet-like conductors and the ground is known. Topographic effects can be removed from VLF data by filtering. For other electromagnetic methods, such as TURAM, topographic corrections are very difficult to make. Magnetic data collected will be biased towards the rocks uphill of the point where the data was collected, as the sensor would be nearer the ground in this direction.

Another factor related to topography is that certain geophysical methods use heavy equipment and generators. Vehicles could only be driven to within 15km of Mangani at the time of the survey. Both IP and many electro-magnetic methods have the drawbacks that transport of the equipment is difficult, and the actual survey takes much time and manpower.

5.5.7 Summary of geophysical methods used at Mangani.

The physical characteristics of mineralisation and the possible effects of lateritic soils and topography have been discussed in the previous sections. Gravity was not used because of the lack of density contrasts and the absence of sufficiently accurate topographic maps. A magnetometer was used, despite the fact that not all mineralisation was detectable. The equipment is portable and data can be collected quickly, so it was felt that enough useful information might be gained to warrant the effort. SP was another method used, as again the equipment was portable and measurement rapid. This method was used in order to detect sulphide zones and disseminations. As steeply dipping sheet conductors such as veins are well detectable by electromagnetic methods, it was considered that VLF should be used. This is the only fast EM method with portable equipment, but the high frequency means that it is particularly affected by lateritic soils. This method also tends to be poor in discriminating poor from good conductors, and produces too many spurious anomalies. For these reasons another, lower frequency electromagnetic method was used (TURAM). This method unfortunately involves transporting heavy equipment, and takes a lot of time. IP equipment was only available at an early stage of the geophysical work at Mangani, and after being carried to the area it broke down. Originally, further investigation of any larger anomalies had been planned using IP, but this was not possible.

5.6 Self potential (SP)

5.6.1 Previous SP work.

A team from the Indonesian Geological Survey (Harsono et al., 1978) covered the part of the Mangani area containing most of the known veins using the SP method (Fig. 16). Locations mentioned in the following discussion are marked in Figure 5.

The equipotential map produced shows a low (-60 mV), but quite extensive negative potential over the southern side of the Mangani Vein, and anomalies of similar magnitude in the Rambutan Tinggi Vein area. The Rambutan and Silver Veins are marked by a large negative area (min -130mV, usually -60mV). The eastern edge of this area is bounded by a complex series of highs and lows, and by large potential gradients.

A number of areas not related to known mineralisation have SP lows. These are marked in Figure 17, as well as areas with geochemical or magnetic anomalies. One area south of the Mangani Vein, containing a number of parallel positive and negative areas may be related to the southern edge of the Mangani Graben. De Haan et al (1933) describe a WNW mineralised fault zone, which appears to cut off the southern end of the Mangani Vein, and which may well be the edge of the Mangani Graben. The SP pattern seen over these veins suggests that the Rambutan and Silver Veins do not extend very far north, but swing west into the edge of the Mangani Graben.

A large area around the Rambutan (Botung Lawas) River, upstream of the junction with the Botung River has a negative anomaly (-30mV). This may be caused by the highly pyritised nature of rocks in this area.

The Rumah Sakit (Hospital) Vein seems to have no associated SP anomaly, and the Rumput Pait Vein is only marked by a small low. These veins do not contain as high a base metal sulphide content as the Mangani Vein, though the Rambutan Vein has a similar composition. The reason for the lack of SP anomaly is not known.

The SP work done by the Indonesian Geological Survey suggests that this method is reasonably effective in identifying areas containing known mineralisation, (60mV), and areas of regional pyritisation (-30mV), though in some places the anomalies are complex, and the Rambutan and Silver Veins produce a composite anomaly.

5.6.2 Basis of the SP method.

The difference in natural earth potentials between two points in the ground can be measured by connecting a millivoltmeter of sufficiently high impedence to two electrodes in the ground. Normal earth potentials are small (0-10 mV), while potentials of hundreds of millivolts can be measured over areas acting as natural battery cells , e.g. over sulphide or graphite bodies. Over sulphides, potentials are generally negative.

Natural earth potentials can be caused by a number of different phenomena. Some potentials are caused by water movement (electro-filtration), and are affected by topography (Telford et al., 1976). In a mountainous area with high rainfall such as Mangani, streaming potentials can create negative anomalies on hill tops. Other temporary currents are called telluric currents and can be induced by short period variations in the earth's magnetic field. These potentials are low (~10 mV/km), but constantly vary in direction and magnitude at any point. Variation with time of measured potentials can be caused by these phenomena. More permanent potentials are caused by the presence of mineralisation.

One explanation of the origin of self potentials due to underground conductors has been put forward by Sato and Mooney (1960):-

An electronic conductor (ore) is in contact with an ionic conductor (groundwater), so there will be an exchange of ions at their surfaces. Self potentials are caused by the oxidation potential difference (Eh) between the substances in solution above the water table and those below. A negative centre can be seen over ore bodies so electrons are being supplied to the top of the ore body, while oxidation of the top of the ore implies a liberation of electrons. The ore body itself, being a good conductor, merely acts as a transport medium for electrons. This explains the presence of potentials over graphite, but does not explain large potentials which exist even when the ore body is completely below the water table.

5.6.3 Field procedures.

Three different methods can be used for measuring self potentials.

a/ One electrode (porous pot) is placed at a base station and the second electrode is moved together with the meter to subsequent points and the potentials related to the base station are measured directly. This method involves long lengths of wire, and usually the base station will be moved periodically in order to cover a larger area, the potential difference between the first and subsequent base stations being added algebraically to each subsequent reading. If possible the base station should be located in an area of no mineralisation, otherwise potentials may not be related to true zero. In the latter case the anomalous patterns are still present, but related to an arbitrary (local) zero.

b/ Two electrodes may be moved along the traverse at a fixed distance apart, so that for the next measurement the rear electrode will occupy the position previously occupied by the front electrode. This means the potential difference is being measured over a particular distance. If these values are added together starting from a particular point which is designated zero, then the same result should be obtained as in the first method. When potentials are added up around a circuit then the same value should be obtained for the first and last point. (Fig. 85a). The measurement obtained between two stations 20m apart should be expressed as mV/m or mV/20m but since the distance between stations is approximately the same, for the sake of simplicity potential differences are referred to as potential gradients.

c/ To avoid cumulative errors from the polarisation of the porous pots, method B can be modified so that instead of moving both pots at the same time, the front pot remains in the same place while the rear pot is moved to the next grid position beyond the front pot. A minor advantage of this method is that only one electrode is moved at a time, though it has to be moved twice as far.

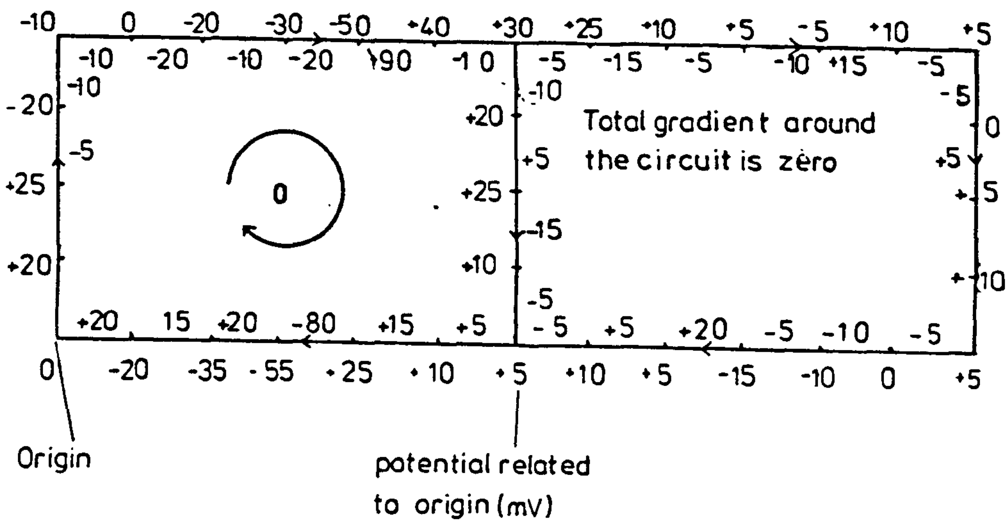
This was the method used at Mangani.

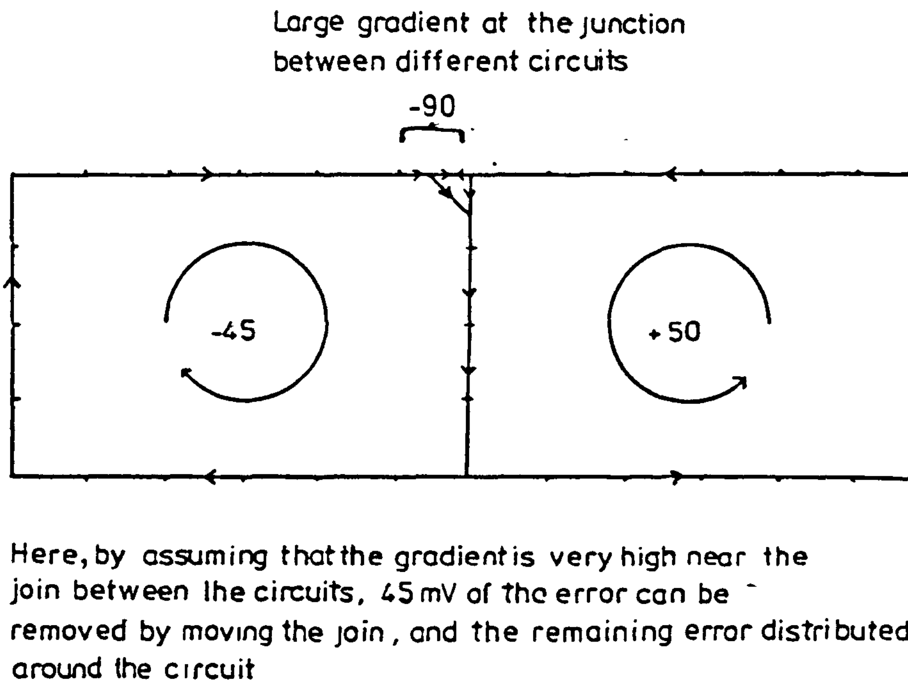
A number of problems arose with the work at Mangani. The rapid daily change of the water table meant that measurements were frequently not repeatable. Relative values between stations were similar, but absolute values varied from day to day. For this reason closure errors were often quite large, being especially high in areas with high potential gradients. In such areas electrodes also had to be placed in exactly the same positions when closing a circuit. Errors of a few cm were found to make a significant difference. Overall these problems are probably not important since potential gradients over some of the known veins were 50-140 mV per 20m, while gradients over unmineralised areas did not exceed 40 mV per 20m.

Smaller closure errors were distributed around the whole circuit, while large gradients were adjusted to remove larger errors. In a few cases adjacent squares showed large errors which were opposite in sign, and where a large potential gradient was present at the grid intersections (Fig. 85b). In these cases usually the potentials had not been measured with the electrodes at identical positions at the intersection point. In one case a large tree had come down on top of the grid position at the intersection of these circuits. The potential had been measured two metres to one side of the grid point, which was enough to cause the error. In these cases when the join between the two circuits was moved slightly the error was cancelled out.

An attempt was made to examine the way in which potentials changed with rainfall, but this proved impossible, since at the same time one place might have a torrential downpour while a kilometre away rainfall was quite moderate.

Figure 85. Example of the method of working out the potential related to a base point from the potential difference measured betweeen two measuring stations, and possible sources of closure errors.





5.6.4 Interpretational theory.

Fig. 86a is taken from Telford et al (1976), and shows the response of a polarised rod dipping at various angles in relation to the ground surface. The SP anomaly on a traverse at a high angle to a vein would approximate to the anomaly over a polarised rod. If the vein is vertical, but the ground slopes, then the effects would be the same as a dipping vein with a flat ground surface, since the angle between the ground surface and the vein is the same.

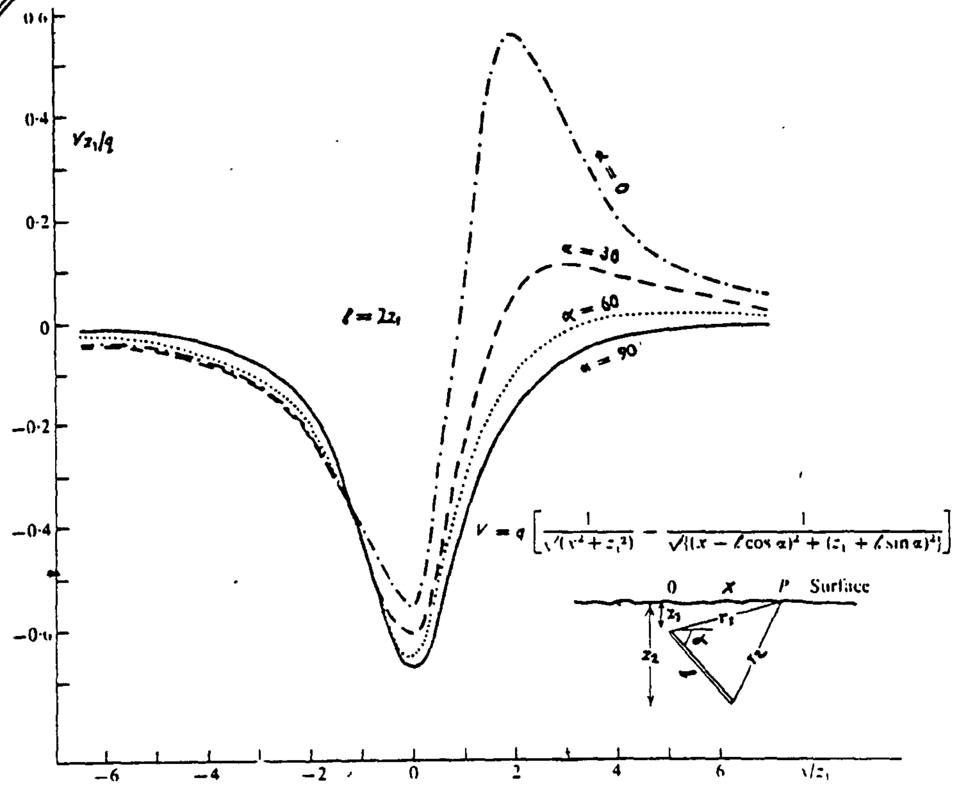
These mathematically calculated potentials match the theoretical ore bodies described by Becker and Telford (1965), as shown in Fig. 86b.

In areas of disseminated mineralization which cause SP anomalies the effect will be similar to that caused by a spherical ore body. Fig. 87d shows the equipotential lines above such a body. Even if the topography is steep the anomaly will be symmetrical, though the largest negative will be located at the point on the ground surface nearest to the centre of the conducting mass, not vertically above it. This means that anomalies may be displaced downhill.

In areas of flat terrain SP anomalies over a vertical conducting body will be symmetrical, with a negative potential centred over the body, flanked by slightly positive potentials, dying away to zero. If the ore body is dipping, then there will be an asymmetric anomaly with a much larger positive wing on the downdip side, and a long negative wing on the other side. The same anomaly style will be produced by a steeply dipping body overlain by steep slopes, as the angle between the ground and the vein will be small. These points are all illustrated in Figure 87. Most veins at Mangani dip quite steeply to the east, so the asymmetry of anomalies will be more marked on east facing slopes. If the vein dips at a shallow angle in the same direction as the slope of the hill, then the effect will be similar to that of a horizontal layer. The Merah Selasa vein is a marked example of such an anomaly. (Line 600S 260E, Fig. 88c)

Figure 86. Self potential profiles produced by ore bodies of differing attitude and shape.

a

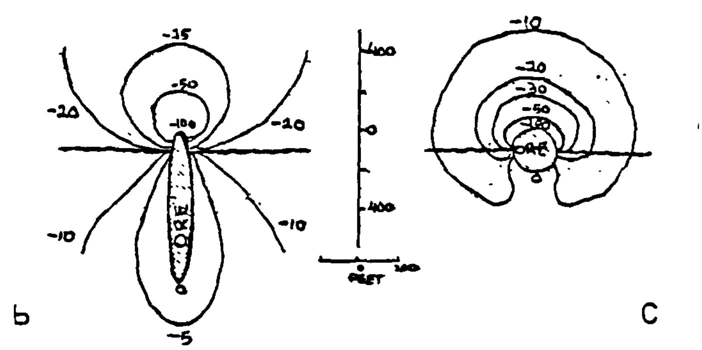


SP profiles over buried polarized rod.

After Telford et al 1976

b

Theoretical model ore bodies for sphere and ellipsoid

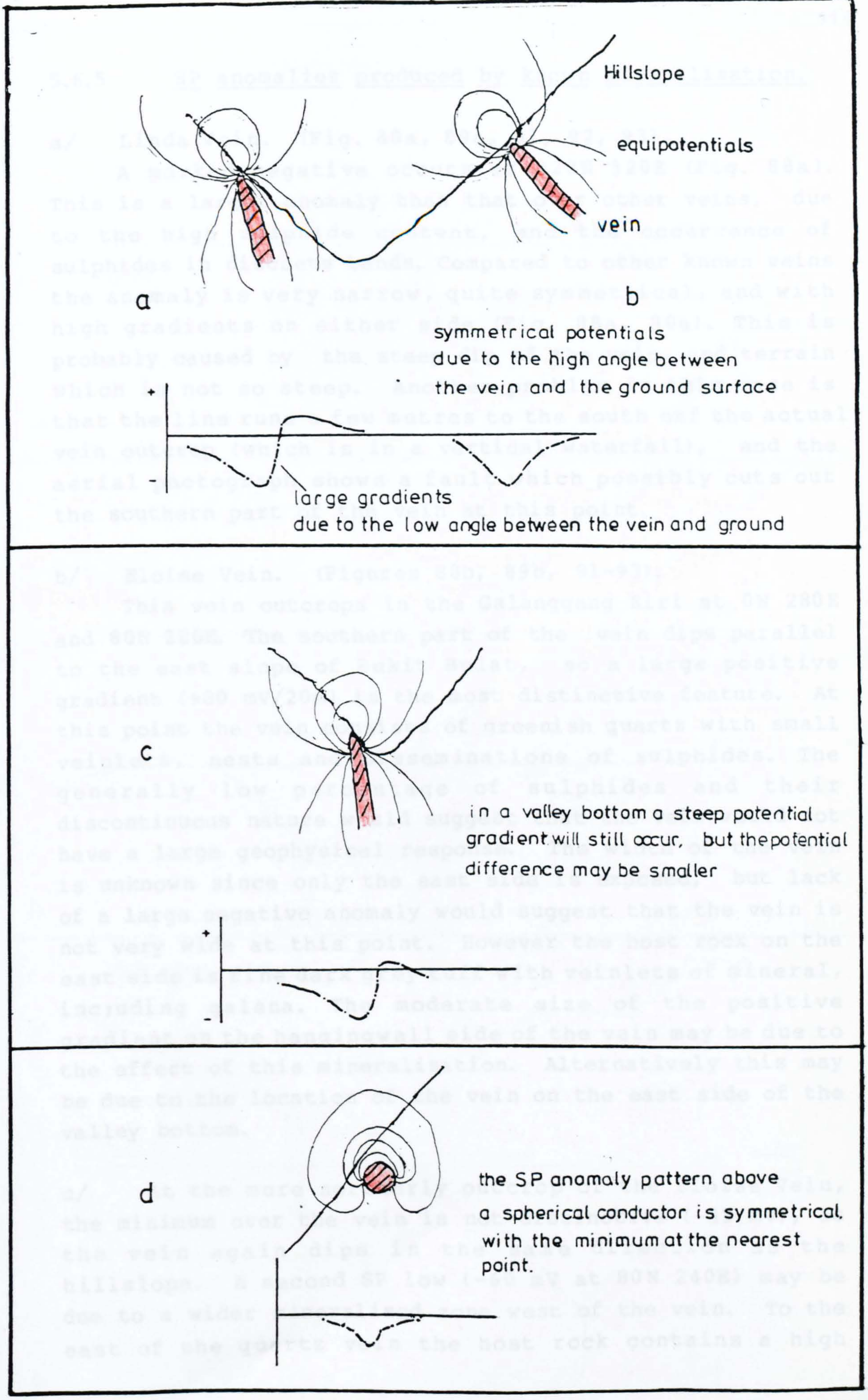


ground surface

equipotential lines

After Becker and Telford 1965

Figure 87. The effect of topography on self potential patterns produced by ore-bodies of differing attitude and shape.



5.6.5 SP anomalies produced by known mineralisation.

a/ Linda Vein. (Fig. 88a, 89a, 91, 92, 93).

A marked negative occurs at 320N 320E (Fig. 88a). This is a larger anomaly than that over other veins, due to the high sulphide content, and the occurrence of sulphides in discrete bands. Compared to other known veins the anomaly is very narrow, quite symmetrical, and with high gradients on either side (Fig. 88a, 90a). This is probably caused by the steep dip of the vein, and terrain which is not so steep. Another problem in this case is that the line runs a few metres to the south oxf the actual vein outcrop (which is in a vertical waterfall), and the aerial photograph shows a fault which possibly cuts out the southern part of the vein at this point.

b/ Eloise Vein. (Figures 88b, 89b, 91-93).

This vein outcrops in the Galanggang Kiri at 0N 280E and 80N 280E. The southern part of the vein dips parallel to the east slope of Bukit Bulat, so a large positive gradient (+80 mV/20m) is the most distinctive feature. At this point the vein consists of greenish quartz with small veinlets, nests and disseminations of sulphides. The generally low percentage of sulphides and their discontinuous nature would suggest that the vein would not have a large geophysical response. The width of the vein is unknown since only the east side is exposed, but lack of a large negative anomaly would suggest that the vein is not very wide at this point. However the host rock on the east side is fine dark grey tuff with veinlets of mineral, inc;uding galena. The moderate size of the positive gradient on the hangingwall side of the vein may be due to the effect of this mineralisation. Alternatively this may be due to the location of the vein on the east side of the valley bottom.

c/ At the more northerly outcrop of the Eloise Vein, the minimum over the vein is not distinctive (-35 mV), as the vein again dips in the same direction as the hillslope. A second SP low (-60 mV at 80N 240E) may be due to a wider mineralised zone west of the vein. To the east of the quartz vein the host rock contains a high

Figure 88. Self potential profiles observed over the Linda, Eloise and Merah Selasa Veins.

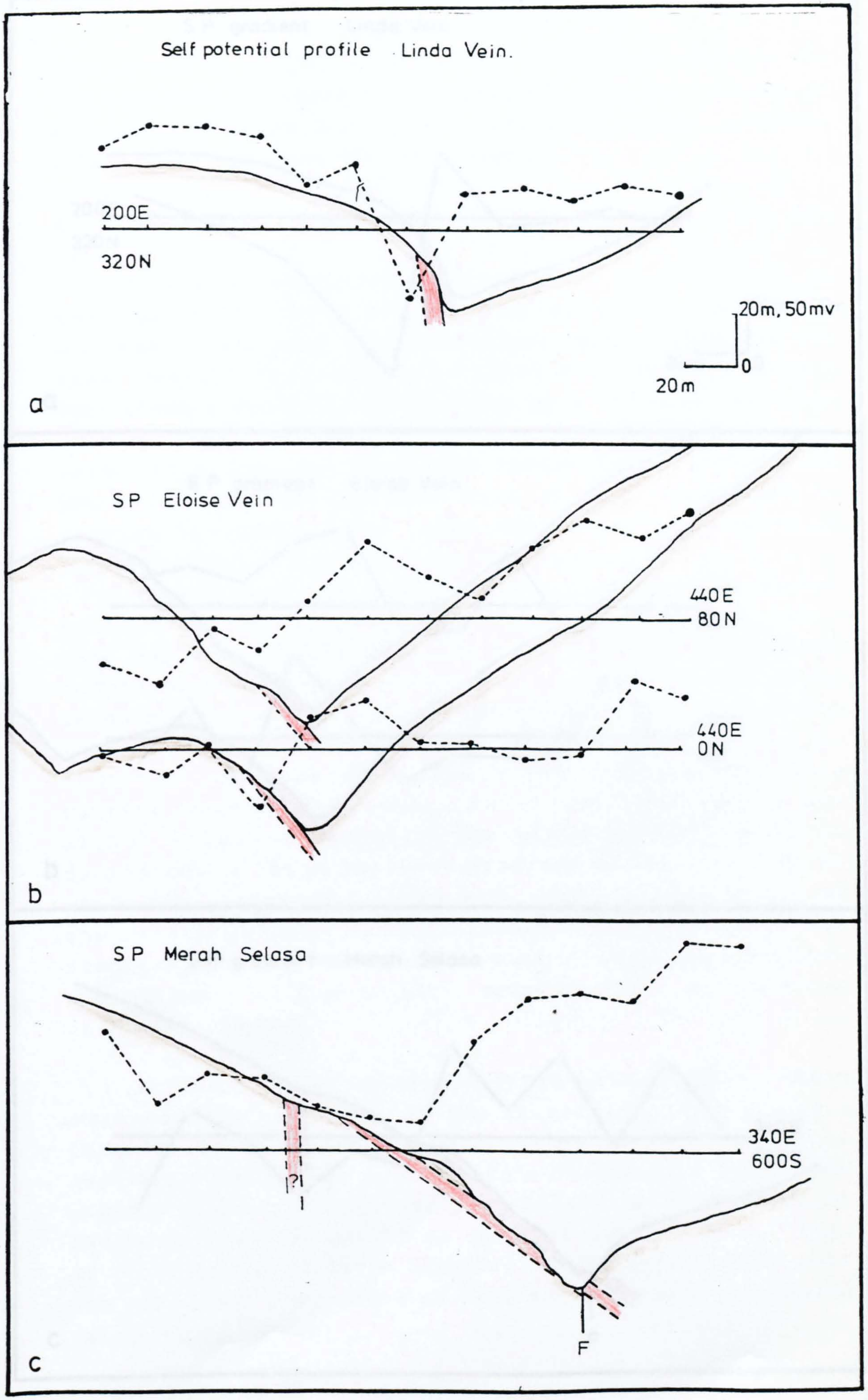
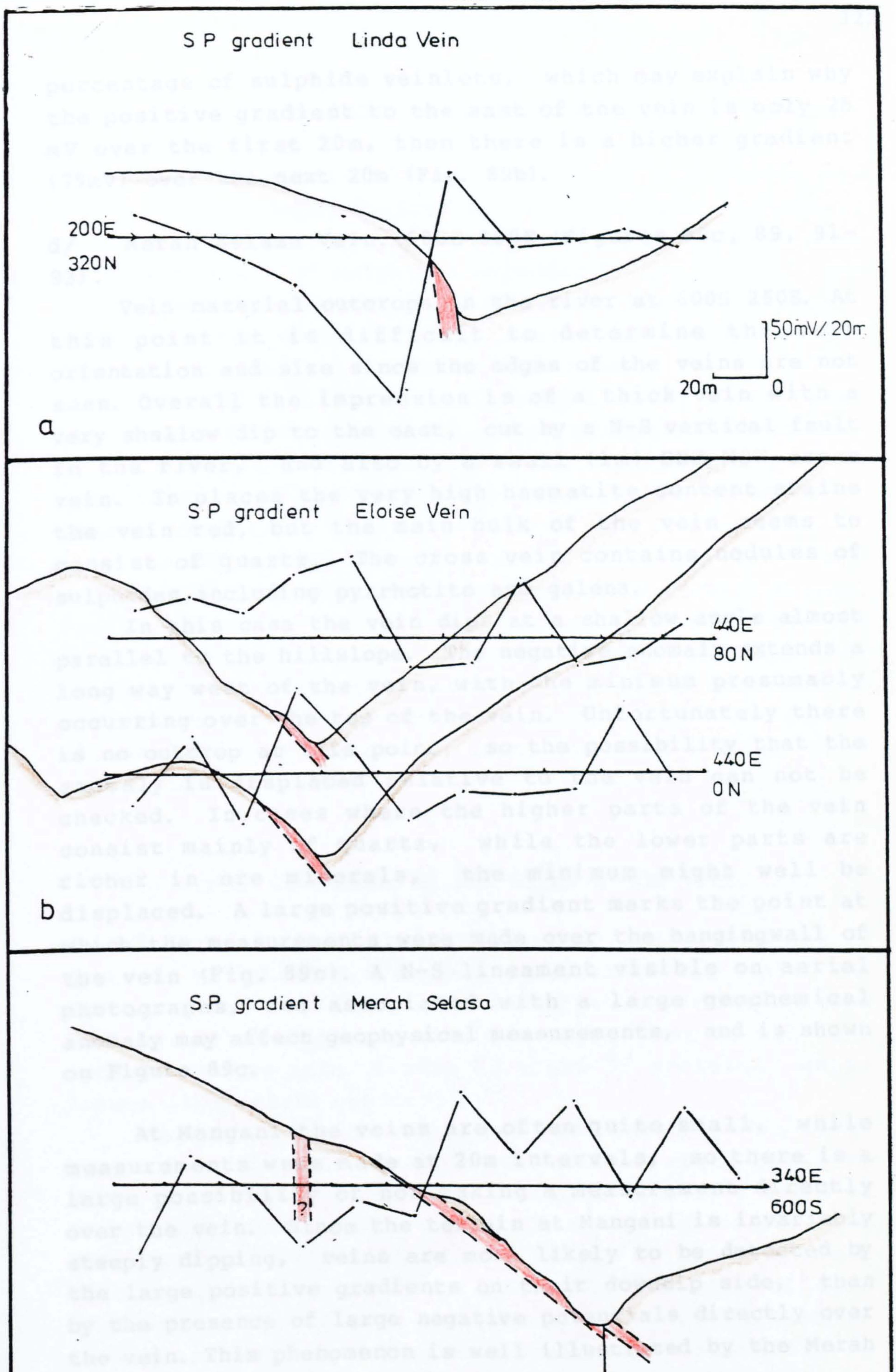


Figure 89. Self potential gradients observed over the Linda, Eloise and Merah Selasa Veins.



percentage of sulphide veinlets, which may explain why the positive gradient to the east of the vein is only 25 mV over the first 20m, then there is a higher gradient (75mV) over the next 20m (Fig. 89b).

d/ Merah Selasa Vein. 600S 260E (Figures 88c, 89, 91-93).

Vein material outcrops in the river at 600S 260E. At this point it is difficult to determine the vein orientation and size since the edges of the veins are not seen. Overall the impression is of a thick vein with a very shallow dip to the east, cut by a N-S vertical fault in the river, and also by a small (1m) ENE-WSW cross vein. In places the very high haematite content stains the vein red, but the main bulk of the vein seems to consist of quartz. The cross vein contains nodules of sulphides including pyrrhotite and galena.

In this case the vein dips at a shallow angle almost parallel to the hillslope. The negative anomaly extends a long way west of the vein, with the minimum presumably occurring over the top of the vein. Unfortunately there is no outcrop at this point, so the possibility that the anomaly is displaced relative to the vein can not be checked. In cases where the higher parts of the vein consist mainly of quartz, while the lower parts are richer in ore minerals, the minimum might well be displaced. A large positive gradient marks the point at which the measurements were made over the hangingwall of the vein (Fig. 89c). A N-S lineament visible on aerial photographs, and associated with a large geochemical anomaly may affect geophysical measurements, and is shown on Figure 89c.

At Mangani the veins are often quite small, while measurements were made at 20m intervals, so there is a large possibility of not making a measurement directly over the vein. Since the terrain at Mangani is invariably steeply dipping, veins are more likely to be detected by the large positive gradients on their downdip side, than by the presence of large negative potentials directly over the vein. This phenomenon is well illustrated by the Merah Selasa Vein.

e/ Reinier, Gorge, Gulley mineralised zone. (160S 340W) (Figures 90-93).

Here the Reinier Vein consists of a discrete N-S quartz vein, though faulted out in the south. The Gulley Vein consists of a N-S trending heavily kaolinised zone with large clots of sulphides embedded in the kaolin, and the Gorge Vein consists of a N-S fault hosted feldspar-porphyry dyke with adjacent lenses of sulphides and altered, mineralised quartzite host rock.

A NW-SE fault zone containing mineral clasts cuts these other N-S features. The clasts within the fault zone do not come from the nearby veins and mineral zones, since they consist of tuff strongly impregnated by bands of mineral (R105).

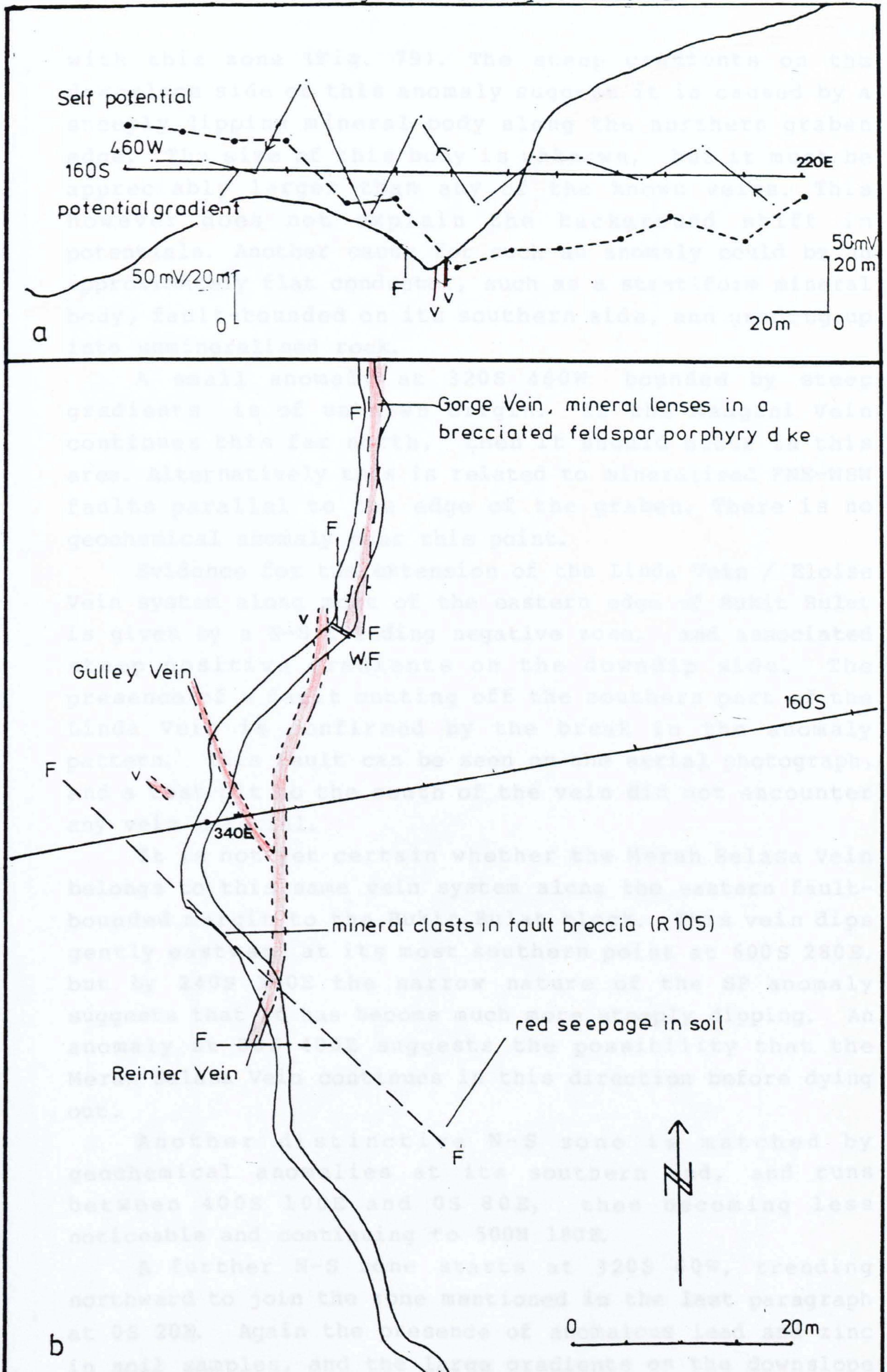
The SP anomaly at this point is large(-80mV) and wide, reflecting the broad nature of the mineralised zone. The zone seems to run in the NW direction rather than to the north suggesting that the N-S oriented veins die away to the north. One explanation for the steep gradient on the west side of this zone is that mineralization is cut off abruptly by the NW-SE fault, but to the NW it dies away gradually.

5.6.6 Self potential in the Bukit Bulat area.

Figure 91 shows the equipotential contours derived from the potential differences measured in the field. An arbitrary zero was designated such that anomalies related to known veins were negative and approximately half the data was below zero. Figure 92 shows SP profiles, while Figure 93 shows SP gradients.

The feature which stands out immediately is the large negative band trending ENE-WSW, with a steep positive gradient on its SW side. There is also clearly a shift in background potentials to the SW. This zone extends between 600S 240E and 240S 340W, for a length of approximately 700m, and a width of about 100m. The location of this feature corresponds with the northern edge of the Mangani Graben as seen on the aerial photograph (Plate 11). A geochemical anomaly of some magnitude is also associated

Figure 90. Self potential and SP gradients over the Reinier, Gorge and Gulley Veins.



with this zone (Fig. 79). The steep gradients on the downslope side of this anomaly suggest it is caused by a steeply dipping mineral body along the northern graben edge. The size of this body is unknown, but it must be appreciably larger than any of the known veins. This however does not explain the background shift in potentials. Another cause for such an anomaly could be an approximately flat conductor, such as a stratiform mineral body, fault-bounded on its southern side, and grading up into unmineralised rock.

A small anomaly at 320S 460W bounded by steep gradients is of unknown origin. If the Mangani Vein continues this far north, then it should occur in this area. Alternatively this is related to mineralised ENE-WSW faults parallel to the edge of the graben. There is no geochemical anomaly near this point.

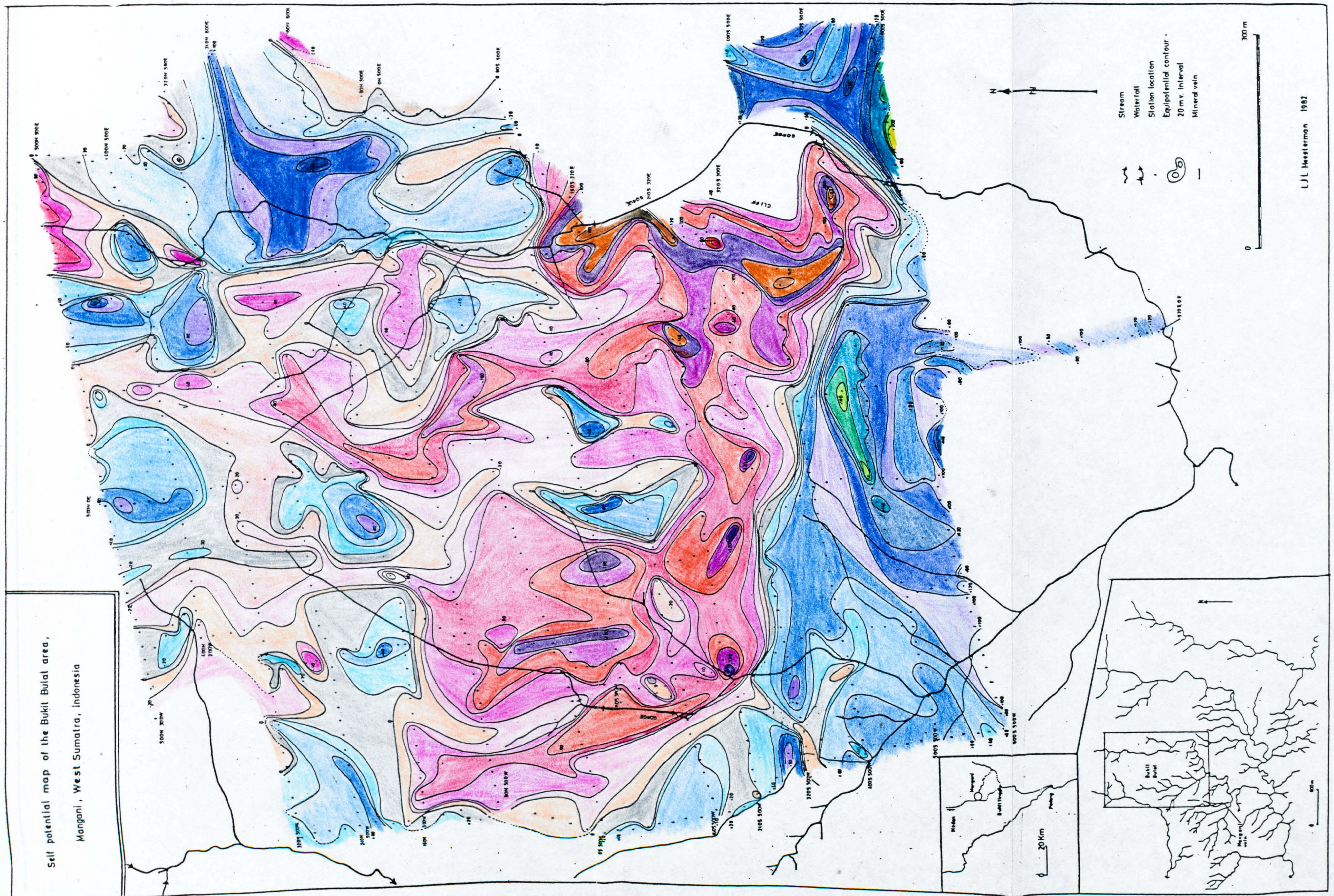
Evidence for the extension of the Linda Vein / Eloise Vein system along most of the eastern edge of Bukit Bulat is given by a N-S trending negative zone, and associated steep positive gradients on the downdip side. The presence of a fault cutting off the southern part of the Linda Vein is confirmed by the break in the anomaly pattern. This fault can be seen on the aerial photograph, and a test pit to the south of the vein did not encounter any vein material.

It is not yet certain whether the Merah Selasa Vein belongs to this same vein system along the eastern fault-bounded margin to the Bukit Bulat block. This vein dips gently eastward at its most southern point at 600S 280E, but by 240S 300E the narrow nature of the SP anomaly suggests that it has become much more steeply dipping. An anomaly at 80S 400E suggests the possibility that the Merah Selasa Vein continues in this direction before dying out.

Another distinctive N-S zone is matched by geochemical anomalies at its southern end, and runs between 400S 100E and 0S 80E, then becoming less noticeable and continuing to 500N 180E.

A further N-S zone starts at 320S 60W, trending northward to join the zone mentioned in the last paragraph at 0S 20E. Again the presence of anomalous lead and zinc in soil samples, and the large gradients on the downslope

Figure 91. Self potential map of the Bukit Bulat area.



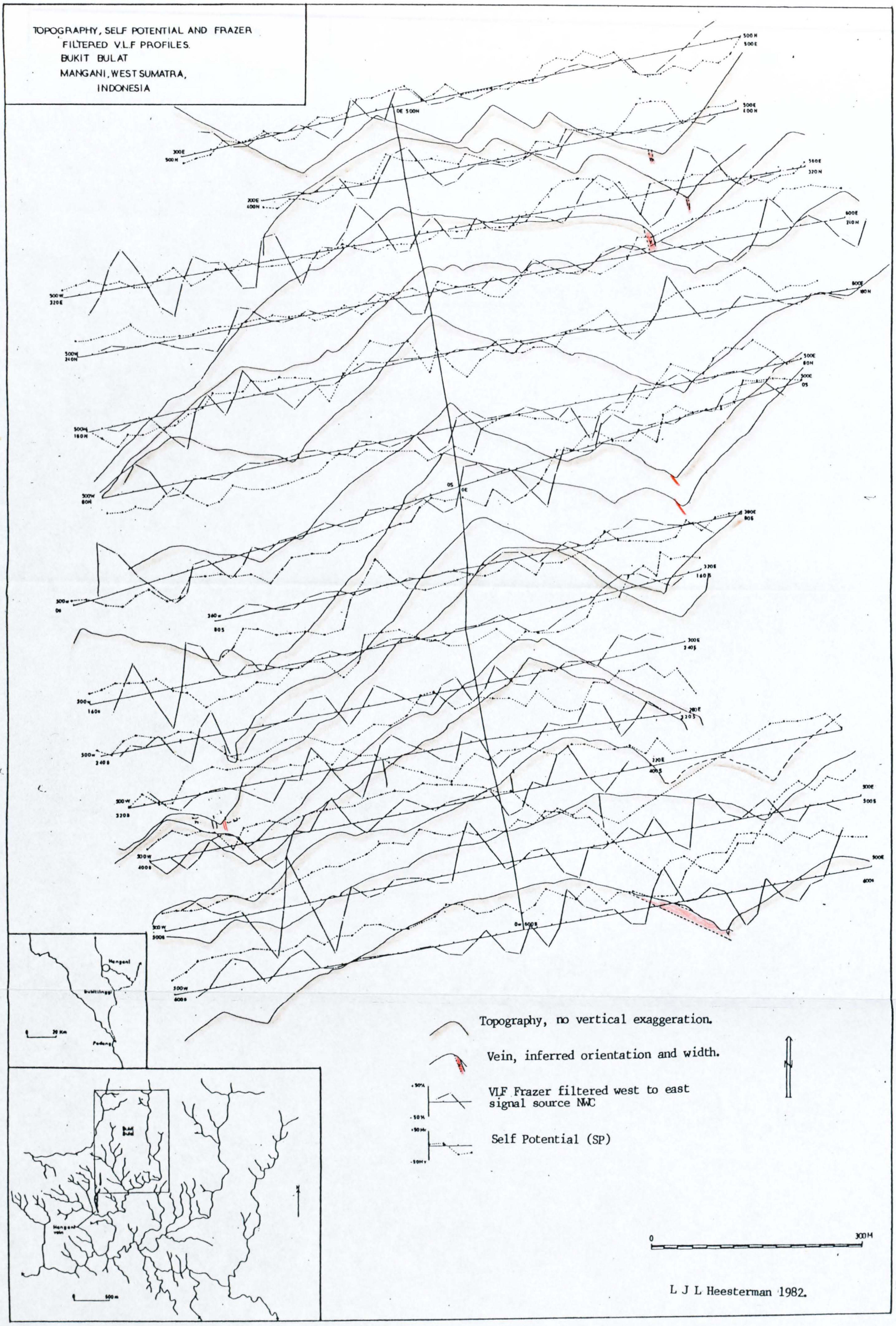


Figure 92. Topography, self potential and Frazer filtered VLF profiles in the Bukit Bulat area.

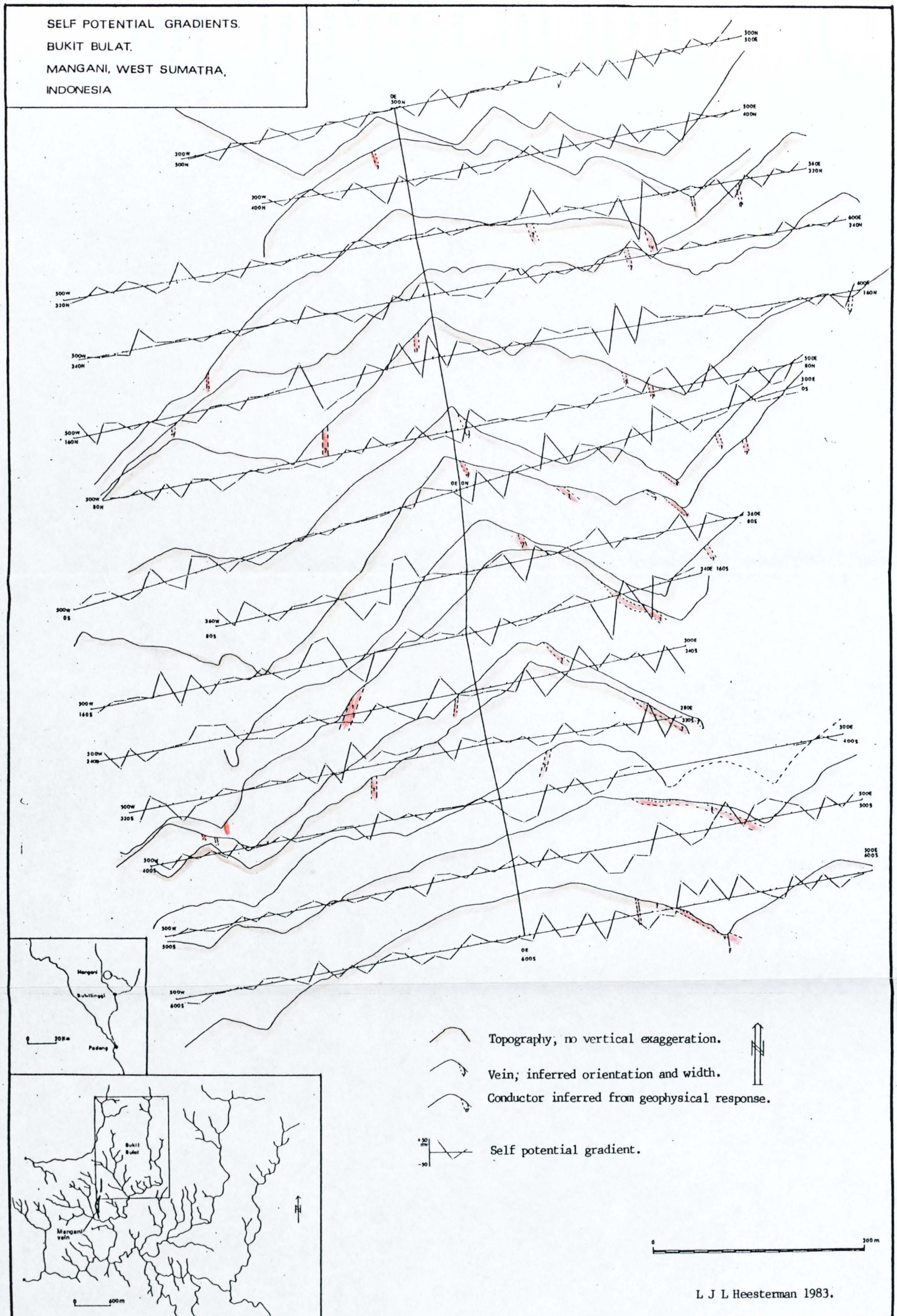


Figure 93. Self potential gradients in the Bukit Bulat area.

side suggest that this may be a steeply dipping vein.

A third N-S negative zone with some associated geochemical anomalies extends from 320S 160W almost exactly to the north.

5.6.7 SP anomalies in the Rambutan-Silver Vein area.

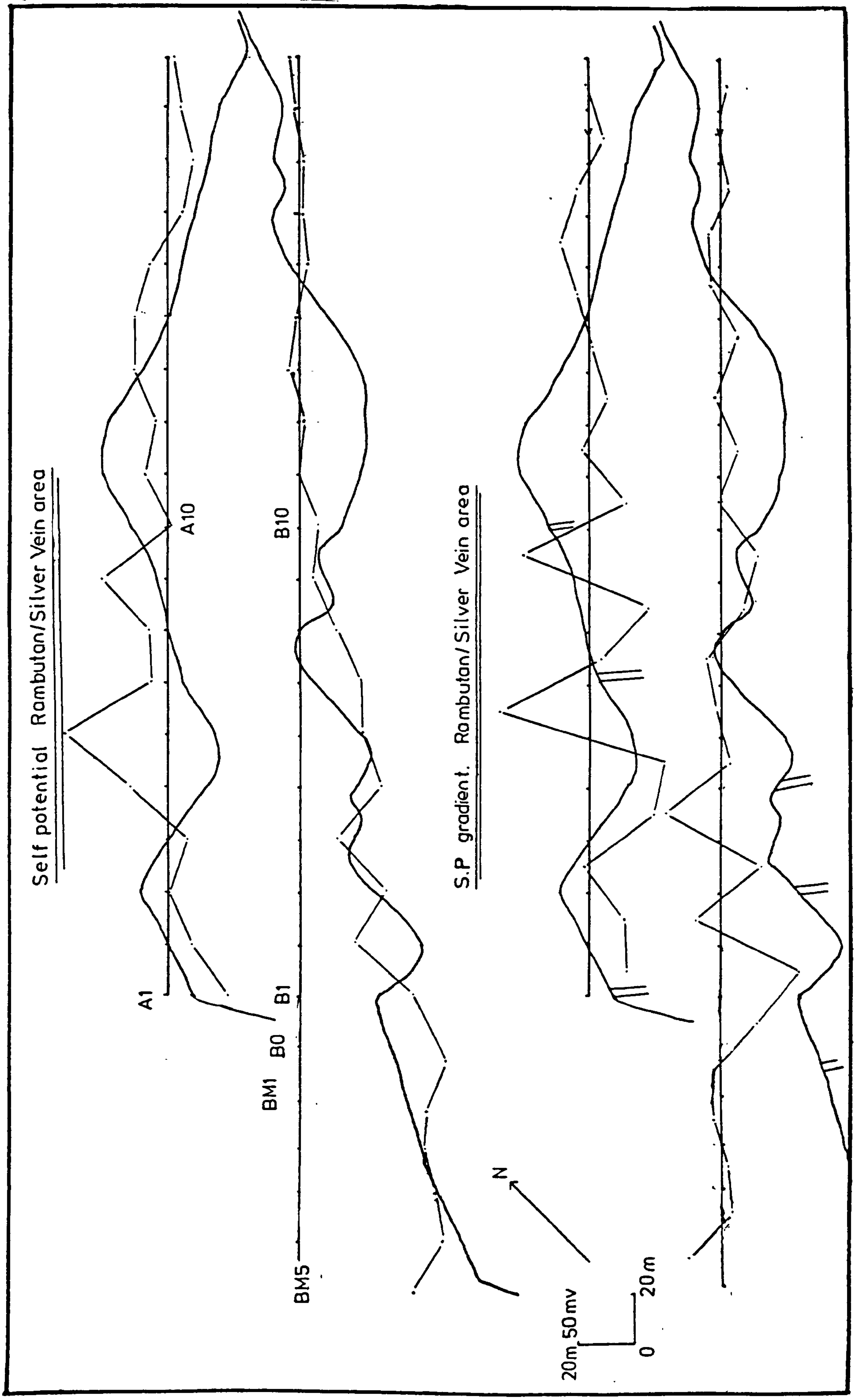
One point immediately noticeable is the lack of anomaly associated with the southern Mangani Graben edge, which is thought to be located between A18 and A19 (Fig. 94). This suggests that Brani Conglomerate and tuff have similar electrical properties, despite the generally more altered nature of the tuff.

The whole of the south western part of the area is noticeably more negative, especially on line B. This SP anomaly pattern is also seen on the SP map produced by D.M.R (Harsono et al., 1978).

Recognition of anomaly trends is unfortunately not facilitated by the oblique orientation of the lines relative to the N-S veins. This line orientation was the only way that the cliffs on either side of the lines could be avoided. The exact location of the Rambutan and Silver Veins along these two lines is not known, and the number of veins present is not certain. In the Rambutan and Gallanggang Rivers on either side of these lines, 3 sets of vein outcrops, as well as smaller veinlets, are known. These may however be the result of fault duplication of two veins (Fig. 98).

Three anomaly lines can be recognised if veins are assumed to be oriented N-S, A10-B5, A6-B3 and A1-BM1. These are likely to be caused by mineralisation rather than fault lines, since the southern Mangani Graben margin has little effect on the SP anomaly pattern.

Figure 94. Self potential and SP gradients in the Rambutan-Silver Vein area.



5.6.8 General conclusions.

General conclusions that can be reached from this data suggest that veins are better picked up by high positive gradients (> 50mV/20m) over the hanging wall, than by negative zones over the vein sub-outcrop. Large negative areas may be related to areas of disseminated sulphides, and do not always have associated geochemical anomalies, so probably contain mainly pyrite. In Bukit Bulat a general reduction in the areas of negative potentials to the north suggests that alteration and mineralisation decrease northward away from the graben edge. Another point of significance is the lack of contrast between different bedrock types. Sihapas Formation quartzites, which probably outcrop just to the north of the graben edge, seem to be just as mineralised as tuffs and carbonaceous shale. This is in contrast with the experiences of earlier Dutch miners. De Haan et al (1933) state that veins in sedimentary host rocks are lower in metal content than veins hosted in volcanics.

5.7 VLF Electromagnetic survey.

5.7.1 Theoretical basis of the VLF method.

Powerful transmitters scattered around the world emit low frequency radio signals used for communication and navigation. The antenna is vertical, so creates a concentric horizontal electric and magnetic field. In radio technology the frequencies of these transmitters (15-25 kHz) are Very Low Frequencies (VLF). In terms of electromagnetic geophysical methods these frequencies are quite high, so the name is misleading.

The magnetic component carries the bulk of the signal energy and is used for H mode VLF. The electric component can be used for E mode VLF. This uses a very long horizontal receiving antenna, so is only practical for airborne surveys.

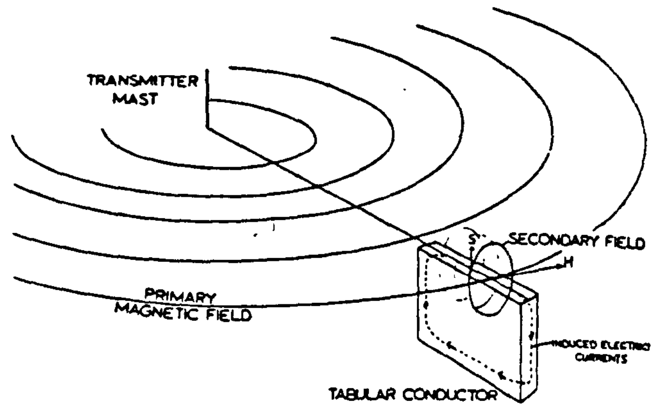
The signal from the antenna is transmitted in three different ways; groundwave, skywave and spacewave. At great distances only the skywave can be received, and then the field can also be assumed to be rectangular. The skywave is guided by the ionosphere and the earth's surface, with vectors approximately parallel to ground surface. Where the ground surface is not flat (e.g. the hills at Mangani), topographically controlled anomalies can be generated. Anomalies due to mineralisation will be superimposed on these.

When the magnetic field travels below the surface it will be attenuated and distorted in phase and direction. Attenuation is one of the limiting factors in the use of VLF. In area of conducting overburden, (e.g. thick lateritic soils) or moderately conductive host rocks, the depth of penetration of the signal will be small. At Mangani soils were generally not thick enough to cause a major problem.

The primary field coupled with a buried conductor, e.g. an ore body, will induce a secondary field (Fig. 95a). The secondary magnetic field differs in phase and direction from the primary field. When the two are added together the resulting field can be described as

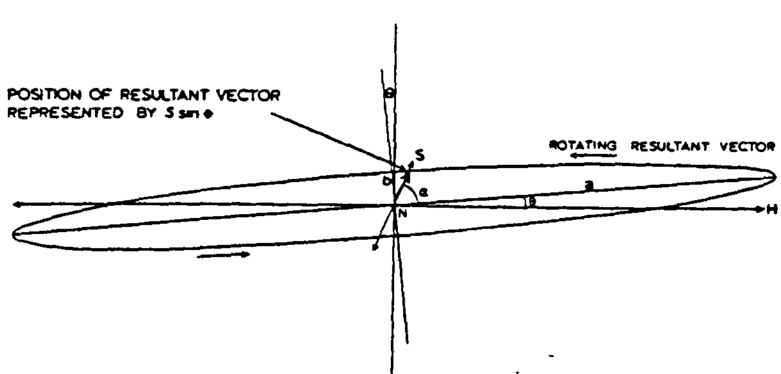
Figure 95.

THE INTERACTION OF A PRIMARY MAGNETIC FIELD WITH A BURIED CONDUCTOR TO PRODUCE A SECONDARY MAGNETIC FIELD.



a

THE POLARISATION ELLIPSE REPRESENTING THE PRODUCT OF THE PRIMARY AND SECONDARY MAGNETIC FIELDS.



Direction of the primary magnetic field.

b

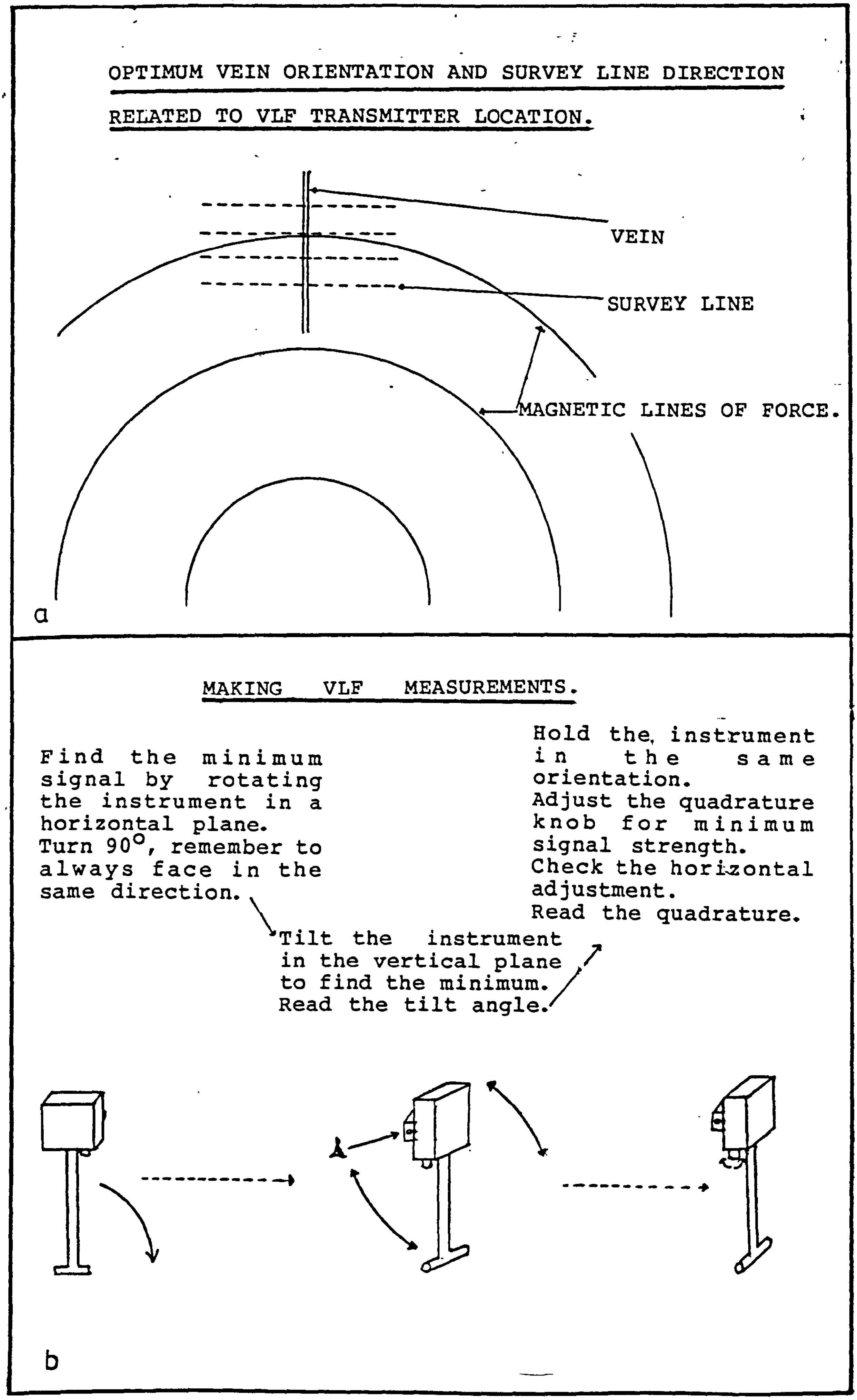
After Phillips and Richards, 1974.

elliptically polarised (Fig. 95b). The mathematical derivation of the equations for the ellipse is shown by Grant and West (1965). The ratio of the long and short axes of the ellipse increase as the phase shift becomes larger, and so is a rough measure of the eccentricity. This is known as the quadrature, or out of phase component. The inclination of the ellipse with regard to the primary field reflects the secondary field strength, and approximates to the real, or in-phase component of the secondary field. The mathematical basis of these assumptions is described by Patterson and Ronka (1971).

5.7.2 Field procedure.

The Geonics EM-16 was used to measure the real and quadrature components of the secondary field. This instrument has two receiving coils set at right angles in the handle. These are aligned with the polarisation ellipse as described in Figure 96b. The angle of tilt is an approximation to the ratio of the real component of the secondary magnetic field to the primary field. The dial can either be read as tilt angle, or as a percentage. The quadrature component is measured by using a proportion of the voltage induced in the reference coil (after shifting its phase through 90°) to compensate the voltage in the signal coil. The quadrature knob reads the percentage of the signal used in the compensation. In order to produce the maximum coupling between the primary field and the conductor, the conductor should be oriented approximately at right angles to the primary field, and to the survey lines (Fig. 96a). For those reasons the radio station NWC (North West Cape) in Australia was used. If the survey line is not oriented at right angles to the conductor, the in-phase and quadrature values will be reduced by cos a, where a is the angle betwen the survey line and the conductor. Readings taken along the line will have maximum measured values of the in-phase and quadrature component, though reception of the primary field is reduced by cos a (Franklin 1973).

Figure 96.


OPTIMUM VEIN ORIENTATION AND SURVEY LINE DIRECTION
RELATED TO VLF TRANSMITTER LOCATION.
VEIN
SURVEY LINE
MAGNETIC LINES OF FORCE.
a
MAKING VLF MEASUREMENTS.
Find the minimum signal by rotating the instrument in a horizontal plane. Turn 90°, remember to always face in the same direction.
Tilt the instrument in the vertical plane to find the minimum. Read the tilt angle.
Hold the instrument in the same orientation. Adjust the quadrature knob for minimum signal strength. Check the horizontal adjustment. Read the quadrature.
b

5.7.3 Interpretational theory.

Two main types of VLF anomaly might be expected at Mangani (Patterson and Ronka 1970), as well as topographic effects.

a/ Veins.

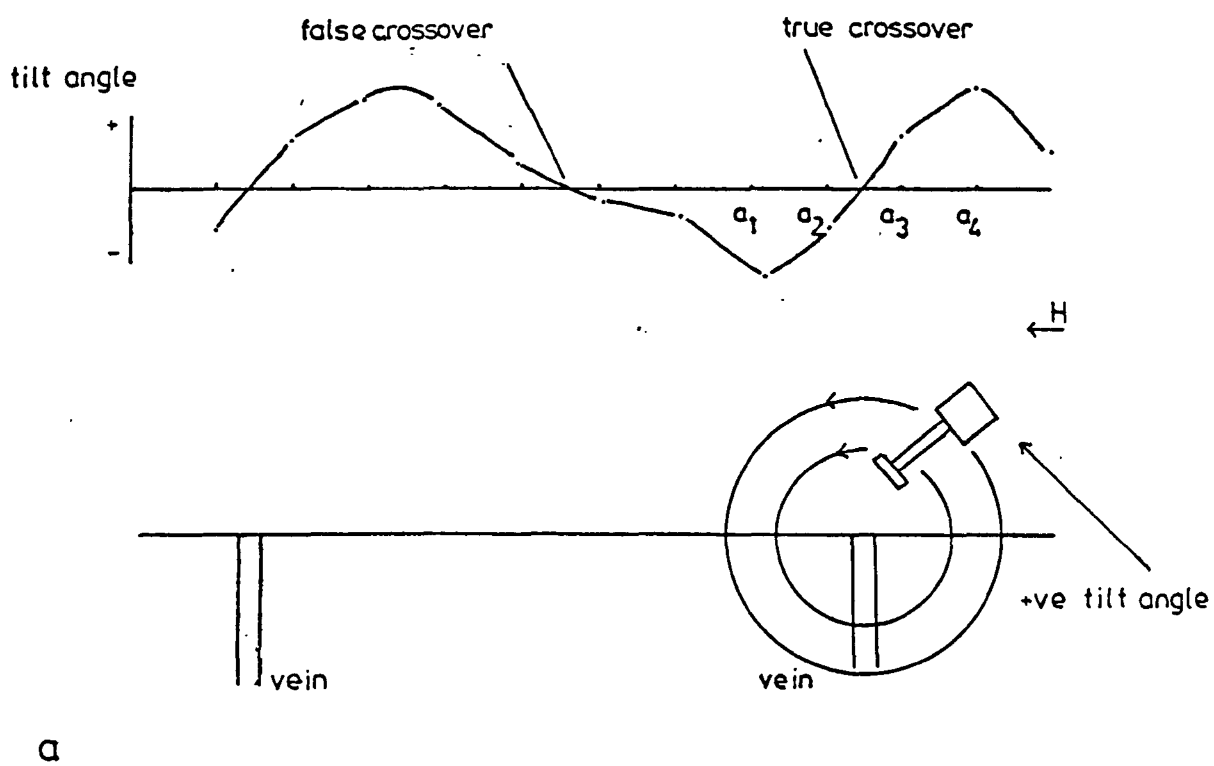
When the ground is uniform the real and quadrature components will be zero. If a line conductor (vein) is present and readings are being taken in the direction of travel, the readings will be positive aproaching the vein, zero over the vein, and negative past the vein (Fig. 97a). If the ground around the vein is conducting as well, then the quadrature component can be opposite in sign to the real component.

The point above the vein where the quadrature component is zero is called a true crossover (between positive and negative). When the influence of one conductor becomes greater than that from another, the tilt angle will also be zero. This is a false crossover (Fig. 97a).

True and false crossovers may be distinguished by the use of Frazer filtering (Frazer 1969).

Conventionally the data are filtered so as to produce a positive anomaly over the conductor. However to facilitate comparison with the SP data, VLF data at Mangani has been filtered so as to produce a negative anomaly. At Mangani the VLF transmitter (NWC) is located to the south east of the area. This means that unfiltered data will have a positive anomaly on the east side of a N/S conducting zone and a negative anomaly to the west. If readings going west to east are $a_1, a_2, a_3, a_4 \ldots a_n$, then $(a_1+a_2)-(a_3+a_4)$ will produce a negative anomaly over the conductor. Frazer filtering also results in smoothed data, and some of the topographic effects will be attenuated. Wittle (1969) suggested the use of the first derivative to remove topographic effects. The Frazer filter uses the first difference (the discrete first derivative) as one of its components.

Figure 97a. True VLF cross overs related to mineralisation, and false cross overs.



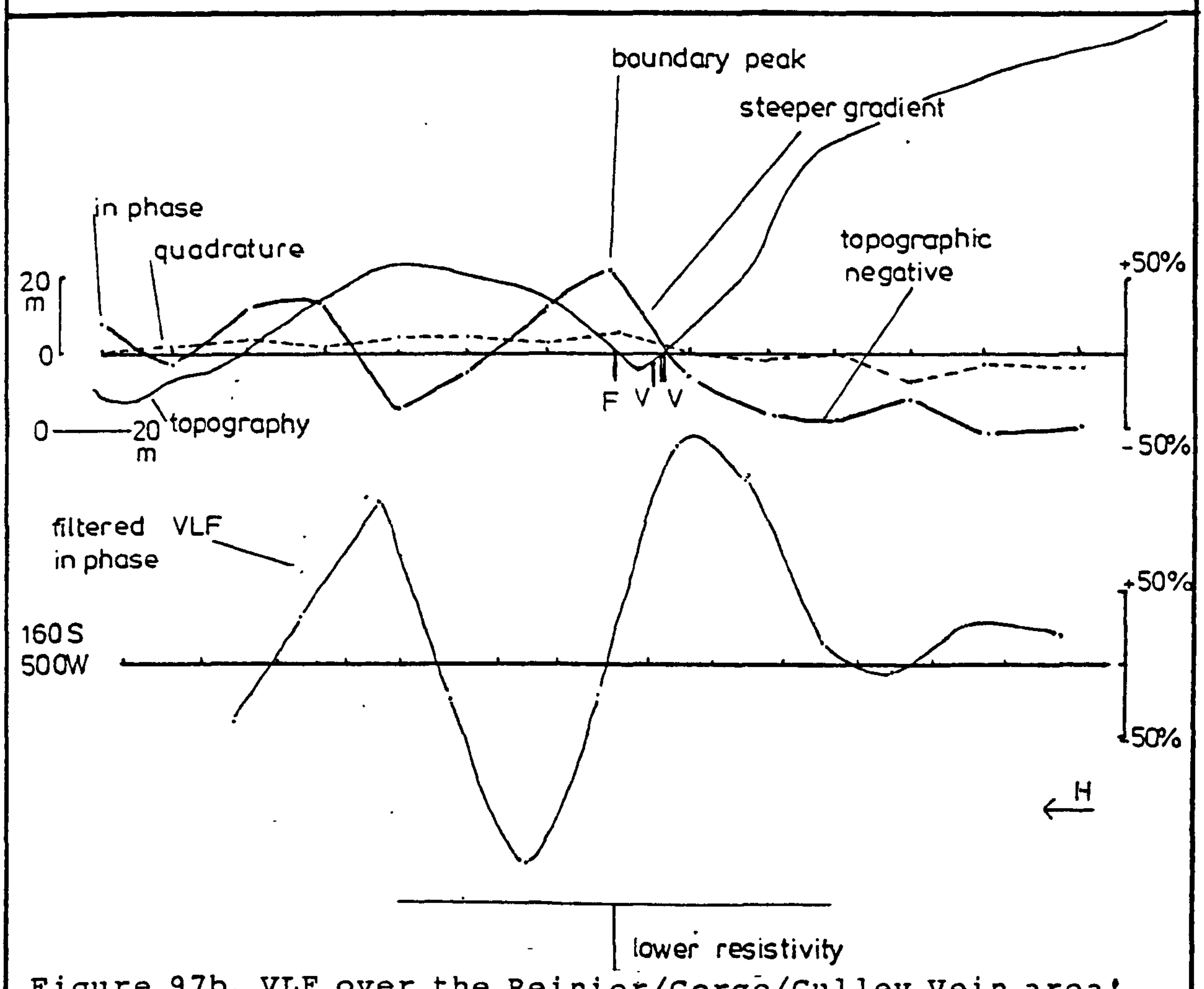


Figure 97b. VLF over the Reinier/Gorge/Gulley Vein area; an example of an anomaly produced at the boundary between layers with different conductivity.

b/ Faults.

The second type of anomaly likely to be encountered is produced over beds of contrasting resistivity (Fig. 97b) (Telford et al., 1976). A positive peak is located over the boundary between the two layers, with the steeper slope over the side with lower resistivity. At Mangani most conductors are so close to each other that anomaly patterns are superimposed. When the data are filtered, the smaller negatives produced by superimposed anomalies may become confused with the small anomalies produced at the west side of a boundary between conducting layers. For this reason such boundary anomalies must first be identified from unfiltered data.

c/ Topographic effects.

When steep-sided ridges are oriented at right angles to the magnetic lines of force the maximum topographic effects are seen. Unfortunately this occurs in the Bukit Bulat area of Mangani. Figure 97b shows that measurements taken on the west slopes of the hill are consistently negative, with superimposed anomalies. Frazer filtering removes most of the effects, though Eberle (1981) suggests that a more sophisticated method should be used. Unfortunately Frazer filtering of topographic anomalies will produce a negative at hill crests, so other data are particularly important in such areas.

d/ Magnetic storms.

Magnetic storms will produce spurious results since the primary magnetic field at the frequency being used, is no longer oriented in the appropriate direction. This does not affect the real component measurements as much, since the orientation of the secondary field depends upon the orientation of the geology. The quadrature component measurements are unfortunately meaningless during a magnetic storm. The only way of knowing if there is a magnetic storm is by the rapid variation of the magnetic field when measured in one place, and by the poor radio reception. Unfortunately during the period when the VLF measurements were made, our magnetometer was not working, so that variations in the magnetic field could not be observed, though radio reception was poor for some of the time.

e/ Effects of magnetic bodies.

If a conducting body is also magnetic, its own magnetic field will be added to the secondary magnetic field, producing a peak, not an inflection point.

5.7.4 <u>VLF response over known veins.</u>

On all diagrams the real and quadrature scale are the same, unless specifically stated.

1/ VLF traverses were made over a number of known veins outside the Bukit Bulat area in order to establish the type of anomaly produced by veins with a low sulphide content, and the displacement between the vein and the anomaly. These traverses were made in stream sections so the exact location of the veins was known and the amount of displacement between the vein and anomaly could be calculated.

Veins investigated in detail are:-

a/ Rambutan and Woolrich Veins. (Fig. 98)

This diagram shows that the minimum in the Frazer filtered data has been displaced by 5-10m down dip. The very shallow fault zone appears to have little effect on the VLF response.

b/ Silver (Perak) Vein. (Fig. 99)

The vein and its anomaly are almost coincident. Unfortunately the deep water in the stream near the dyke prevented the examination of its VLF response. One of the smaller veins seems to have a slightly displaced small anomaly associated with it, and the fault in the western part of the area has an anomaly which is only slightly smaller than that shown by the vein.

c/ The northern extension of the Rambutan and Silver vein in the Galanggang River. (Camp and Peter Veins, Fig. 100).

The points at which the traverse crossed these veins were unfortunately structurally complex. An anomaly is

Figure 98.

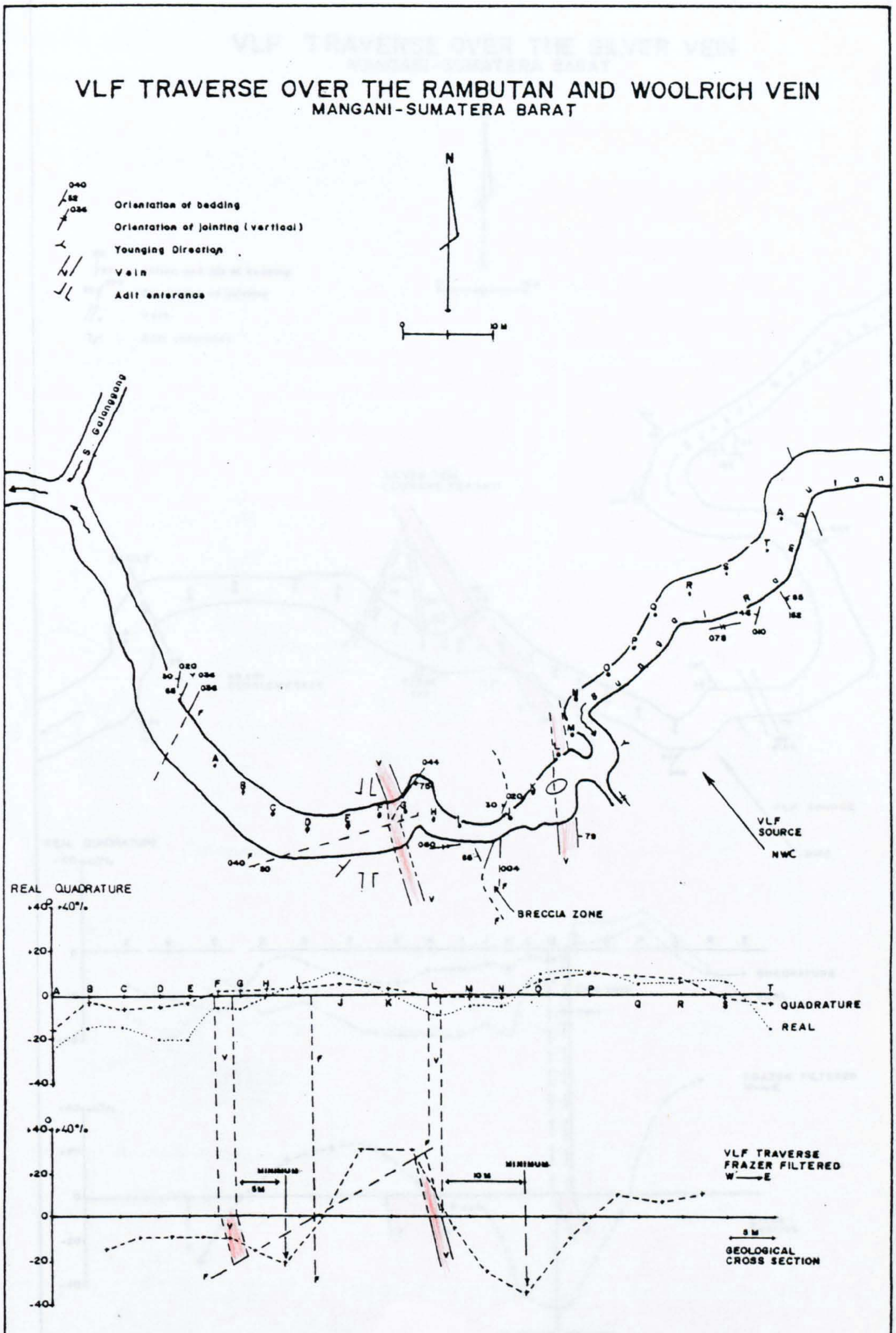

VLF TRAVERSE OVER THE RAMBUTAN AND WOOLRICH VEIN
MANGANI-SUMATERA BARAT
Orientation of bedding
Orientation of jointing (vertical)
Younging Direction
Vein
Adit enterance
N
S. Galanggang
VLF SOURCE
NWC
BRECCIA ZONE
REAL QUADRATURE
QUADRATURE
REAL
MINIMUM
MINIMUM
VLF TRAVERSE
FRAZER FILTERED
W → E
GEOLOGICAL
CROSS SECTION

Figure 99.

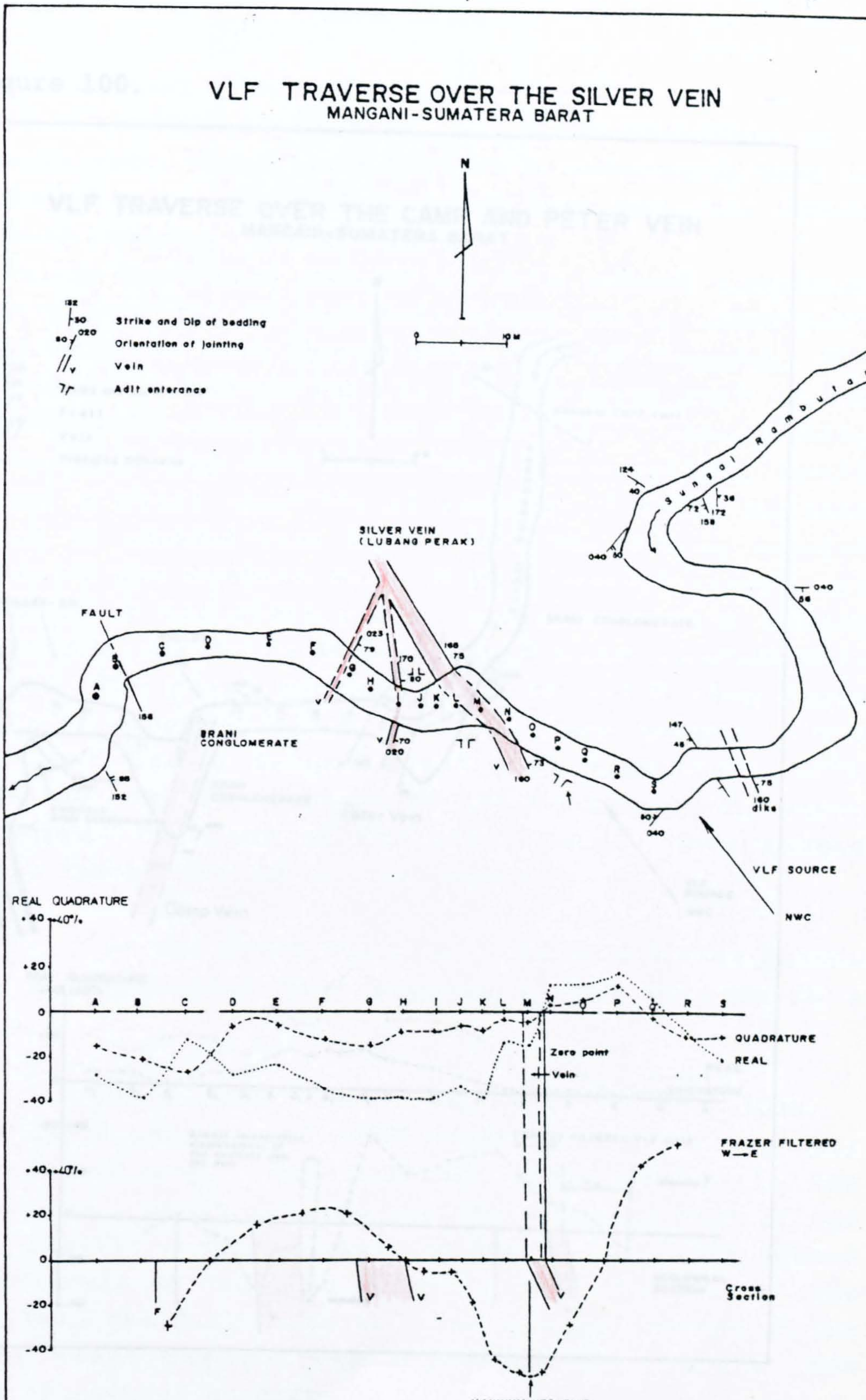
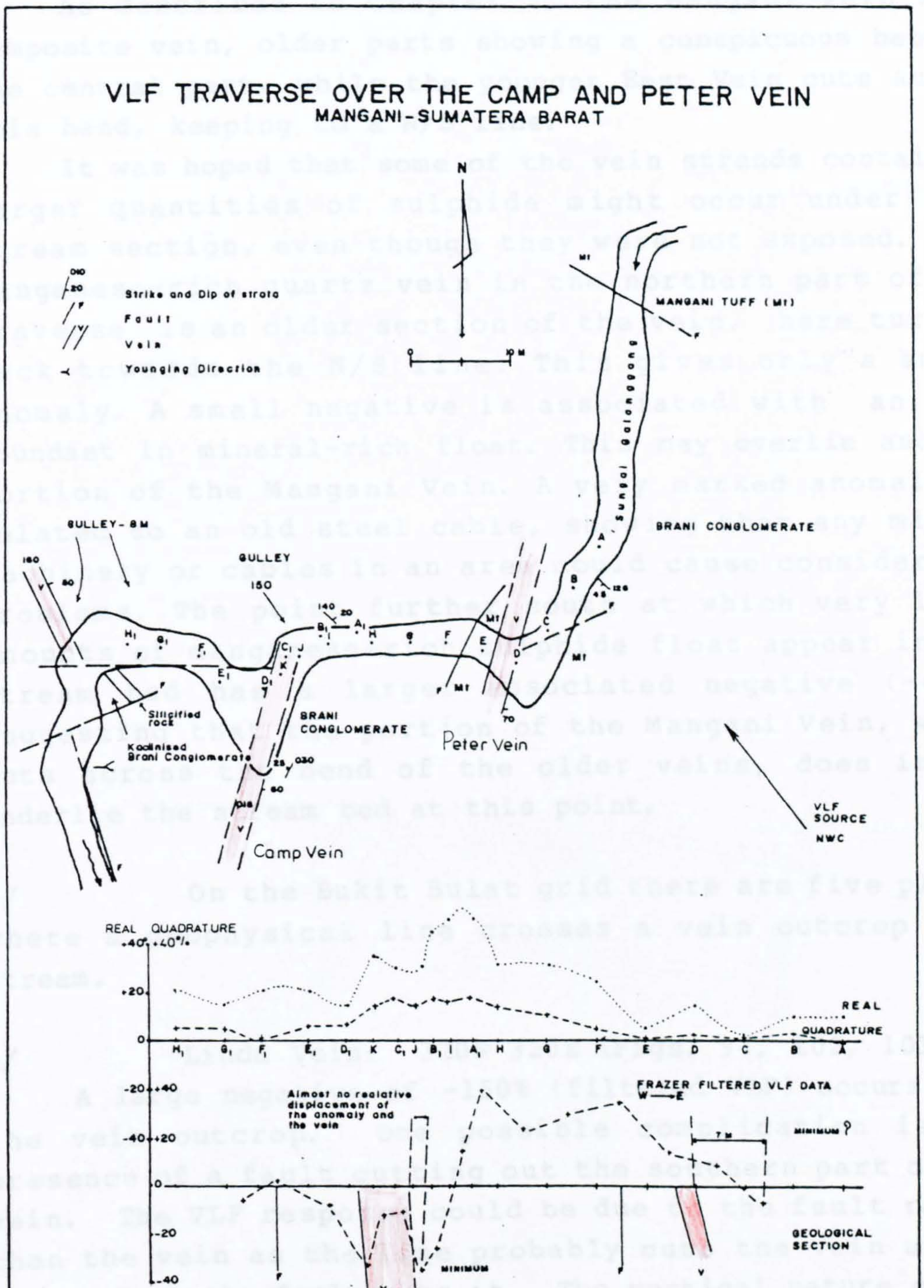

VLF TRAVERSE OVER THE SILVER VEIN
MANGANI-SUMATERA BARAT
N
Strike and Dip of bedding
Orientation of jointing
Vein
Adit enterance
Sungai Rambutan
SILVER VEIN
(LUBANG PERAK)
FAULT
BRANI
CONGLOMERATE
VLF SOURCE
NWC
REAL QUADRATURE
QUADRATURE
REAL
Zero point
Vein
FRAZER FILTERED
W → E
Cross Section
MAXIMUM NEGATIVE

Figure 100.


VLF TRAVERSE OVER THE CAMP AND PETER VEIN
MANGANI-SUMATERA BARAT
N
Strike and Dip of strata
Fault
Vein
Younging Direction
MANGANI TUFF (Mt)
BRANI CONGLOMERATE
GULLEY-8M
GULLEY
Silicified rock
Kaolinised Brani Conglomerate
BRANI CONGLOMERATE
Peter Vein
Camp Vein
VLF SOURCE
NWC
REAL QUADRATURE
REAL
QUADRATURE
FRAZER FILTERED VLF DATA
Almost no relative displacement of the anomaly and the vein
MINIMUM ?
MINIMUM
GEOLOGICAL SECTION

associated with both the veins, but it is not clear what contribution the faults have made.

d/ The Mangani Vein. (Fig. 101)

As described in Chapter 4, the Mangani Vein is a composite vein, older parts showing a conspicuous bend in the central part, while the younger East Vein cuts across this bend, keeping to a N/S line.

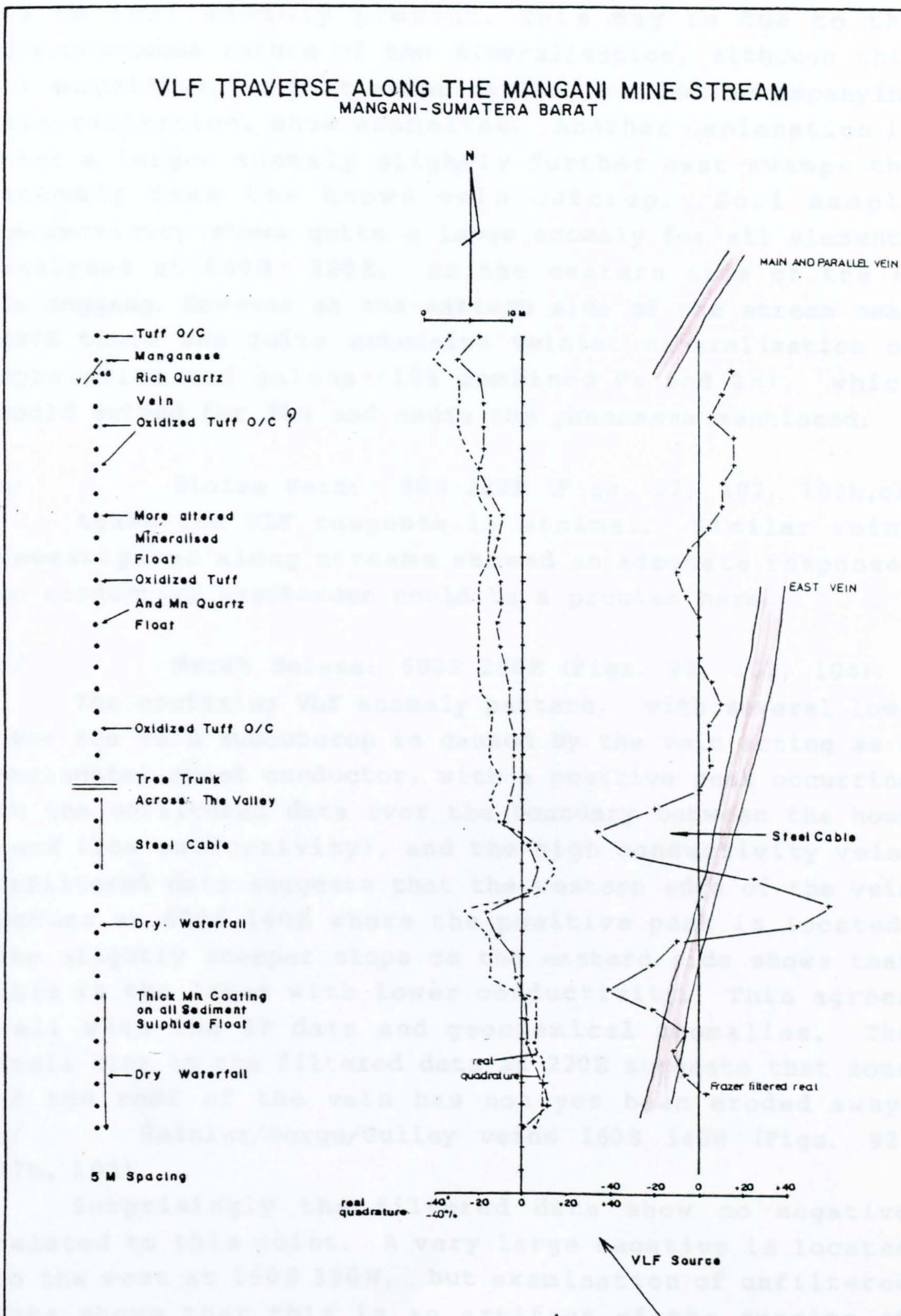
It was hoped that some of the vein strands containing larger quantities of sulphide might occur under this stream section, even though they were not exposed. The manganese-rich quartz vein in the northern part of the traverse is an older section of the vein, here turning back towards the N/S line. This gives only a small anomaly. A small negative is associated with an area abundant in mineral-rich float. This may overlie another portion of the Mangani Vein. A very marked anomaly is related to an old steel cable, showing that any mining machinery or cables in an area could cause considerable problems. The point further south at which very large amounts of manganese-rich sulphide float appear in the stream bed has a larger associated negative (-40^{o}), suggesting that the portion of the Mangani Vein, which cuts across the bend of the older veins, does indeed underlie the stream bed at this point.

2/ On the Bukit Bulat grid there are five places where a geophysical line crosses a vein outcrop in a stream.

a/ Linda Vein: 320N 320E (Figs. 94, 102, 103a).

A large negative of -150% (filtered VLF) occurs over the vein outcrop. One possible complication is the presence of a fault cutting out the southern part of the vein. The VLF response could be due to the fault rather than the vein as the line probably cuts the vein at the point where the fault cuts it. The vertical nature of the outcrop meant that it was impossible to run the line across the actual outcrop.

Figure 101.


VLF TRAVERSE ALONG THE MANGANI MINE STREAM
MANGANI-SUMATERA BARAT
N
0
10 M
Tuff O/C
Manganese
Rich Quartz
Vein
Oxidized Tuff O/C
More altered
Mineralised
Float
Oxidized Tuff
And Mn Quartz
Float
Oxidized Tuff O/C
Tree Trunk
Across The Valley
Steel Cable
Dry Waterfall
Thick Mn Coating
on all Sediment
Sulphide Float
Dry Waterfall
5 M Spacing
MAIN AND PARALLEL VEIN
EAST VEIN
Steel Cable
real
quadrature
Frazer filtered real
-40 -20 0 +20 +40
-40 -20 0 +20 +40
real
quadrature
VLF Source
NWC

b/ Eloise Vein: 0N 280E (Fig. 92, 102, 103b,c)

The VLF data are very ambiguous at this point, there is no real anomaly present. This may be due to the discontinuous nature of the mineralisation, although this is surprising, as most other faults, without accompanying mineralisation, show anomalies. Another explanation is that a larger anomaly slightly further east swamps the anomaly from the known vein outcrop. Soil sample geochemistry shows quite a large anomaly for all elements analysed at 000S 320E, on the eastern side of the A. Galanggang. However at the eastern side of the stream near 280E there was quite extensive veinlet mineralization of sphalerite and galena (10% combined Pb and Zn), which could extend for 30m and cause the phenomena mentioned.

c/ Eloise Vein: 80N 280E (Figs. 92, 102, 103b,c).

Again the VLF response is minimal. Similar veins investigated along streams showed an adequate response, so conductive overburden could be a problem here.

d/ Merah Selasa: 600S 260E (Figs. 92, 102, 104).

The confusing VLF anomaly pattern, with several lows over the vein suboutcrop is caused by the vein acting as a horizontal sheet conductor, with a positive peak occurring in the unfiltered data over the boundary between the host rock (low conductivity), and the high conductivity vein. Unfiltered data suggests that the western edge of the vein occurs at 600S 180E where the positive peak is located. The slightly steeper slope on the eastern side shows that this is the layer with lower conductivity. This agrees well with the SP data and geochemical anomalies. The small kink in the filtered data at 220E suggests that some of the roof of the vein has not yet been eroded away.

e/ Reinier/Gorge/Gulley veins 160S 340W (Figs. 92, 97b, 102)

Surprisingly the filtered data show no negative related to this point. A very large negative is located to the west at 160S 390W, but examination of unfiltered data shows that this is an artifact of the spacing of highs and lows relating to a boundary. A peak at 160S 360W, with a steeper gradient on its eastern side, is caused by the boundary with a more conductive layer to the

Figure 102. VLF profiles in the Bukit Bulat area.

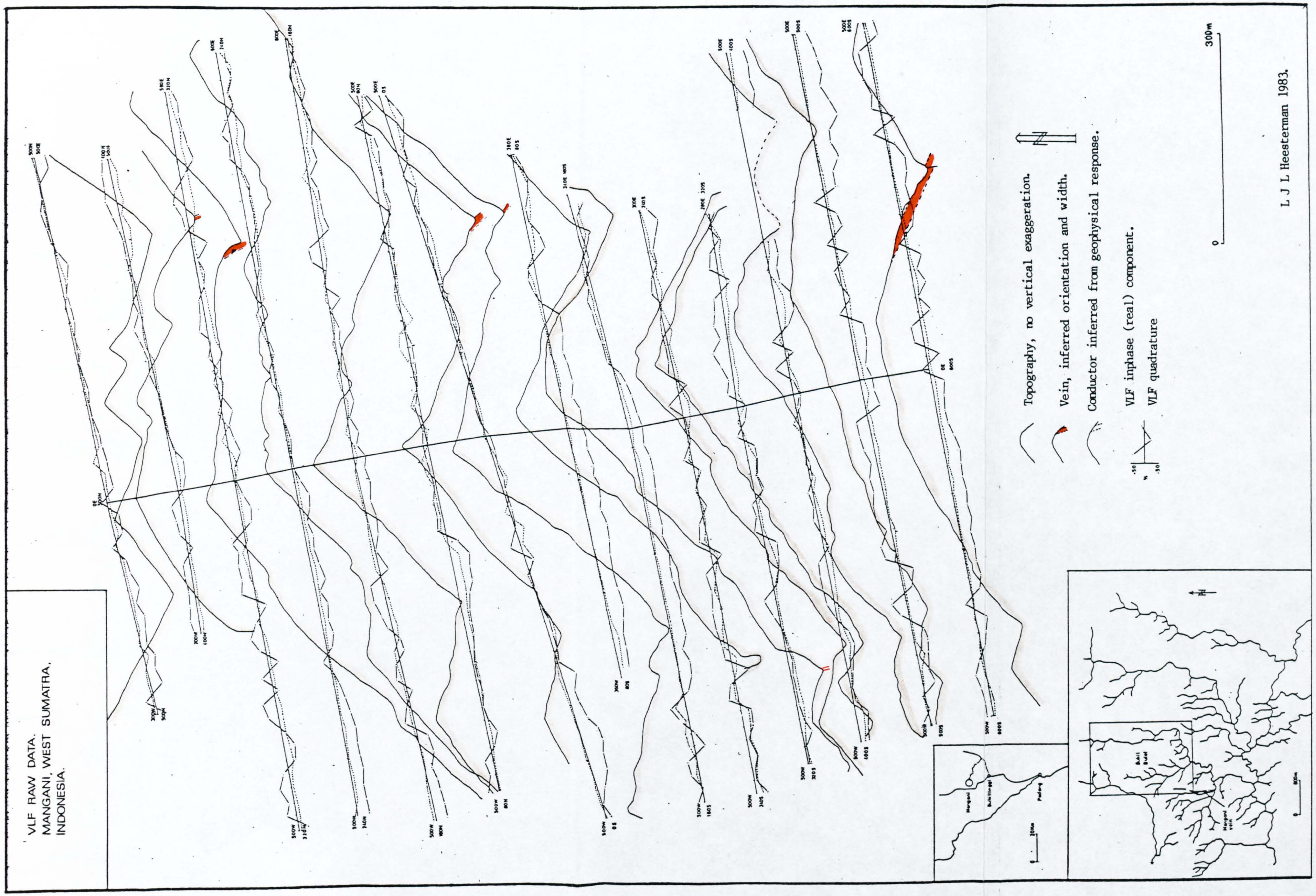


Figure 103. VLF, and Frazer filtered VLF over the Linda and Eloise Veins.

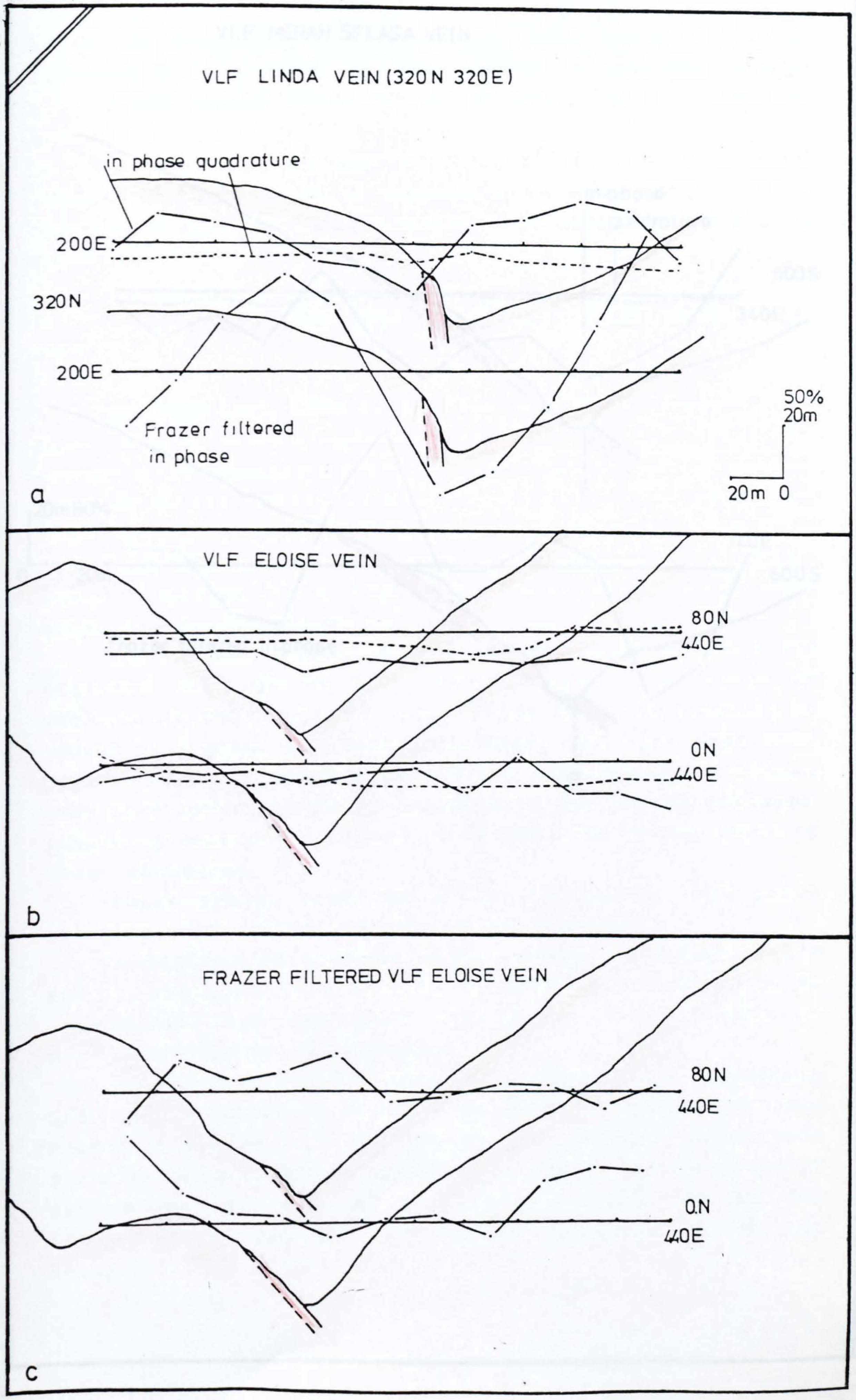
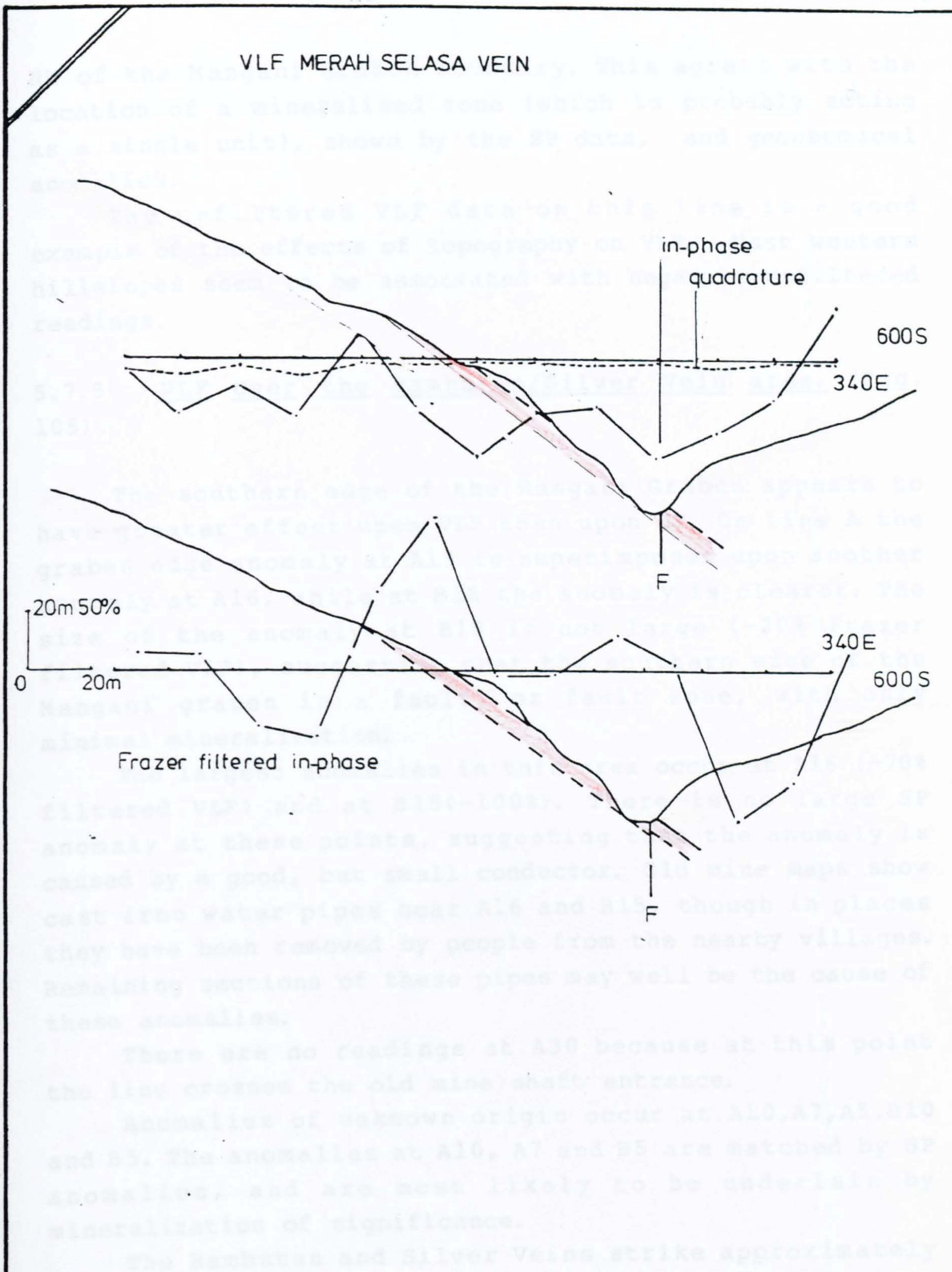


Figure 104. VLF, and Frazer filtered VLF over the Merah Selasa Vein.



NW of the Mangani Graben boundary. This agrees with the location of a mineralised zone (which is probably acting as a single unit), shown by the SP data, and geochemical anomalies.

The unfiltered VLF data on this line is a good example of the effects of topography on VLF. Most western hillslopes seem to be associated with negative unfiltered readings.

5.7.5 VLF over the Rambutan/Silver Vein area. (Fig. 105).

The southern edge of the Mangani Graben appears to have greater effect upon VLF than upon SP. On line A the graben edge anomaly at A19 is superimposed upon another anomaly at A16, while at B18 the anomaly is clearer. The size of the anomaly at B18 is not large (-20% Frazer filtered VLF), suggesting that the southern edge of the Mangani graben is a fault, or fault zone, with only minimal mineralization.

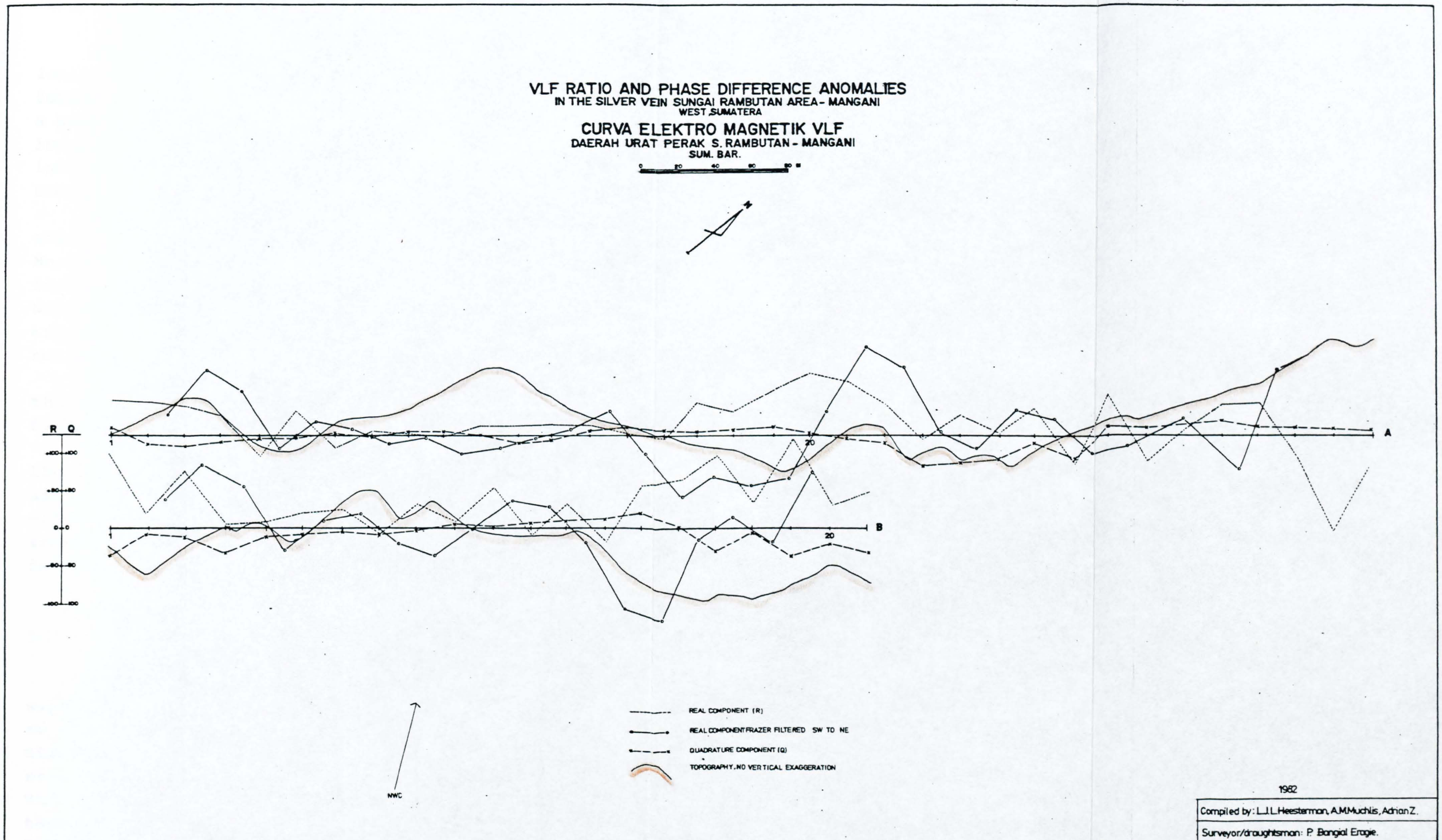
The largest anomalies in this area occur at A16 (-70% filtered VLF) and at B15(-100%). There is no large SP anomaly at these points, suggesting that the anomaly is caused by a good, but small conductor. Old mine maps show cast iron water pipes near A16 and B15, though in places they have been removed by people from the nearby villages. Remaining sections of these pipes may well be the cause of these anomalies.

There are no readings at A30 because at this point the line crosses the old mine shaft entrance.

Anomalies of unknown origin occur at A10,A7,A5,B10 and B5. The anomalies at A10, A7 and B5 are matched by SP anomalies, and are most likely to be underlain by mineralization of significance.

The Rambutan and Silver Veins strike approximately N/S, and so intersect these lines at a low angle. For this reason anomalies will be smaller than in other areas with more suitable line orientation. The Rambutan Vein probably occurs near A1, and the Silver Vein at A10 and B5. The anomaly at A7 may well be another branch of the Silver Vein.

Figure 105.


VLF RATIO AND PHASE DIFFERENCE ANOMALIES
IN THE SILVER VEIN SUNGAI RAMBUTAN AREA - MANGANI
WEST SUMATERA
CURVA ELEKTRO MAGNETIK VLF
DAERAH URAT PERAK S. RAMBUTAN - MANGANI
SUM. BAR.
0
20
40
60
80 m
R
Q
A
B
1
20
REAL COMPONENT (R)
REAL COMPONENT FRAZER FILTERED SW TO NE
QUADRATURE COMPONENT (Q)
TOPOGRAPHY. NO VERTICAL EXAGGERATION
NWC
1982
Compiled by: L.J.L.Heesterman, A.M.Muchlis, Adrian Z.
Surveyor/draughtsman: P. Bangial Eragie.

5.7.6 VLF over the Rumah Sakit (Hospital) Vein area. (Encl. 4)

VLF measurements were made at approximately 25m intervals along paths in this area. Most of these paths follow ridge crests, so topographic anomalies are less of a problem. Every fourth reading occurs at a soil sample location used in 1980. Readings were taken in this way, as information could be gained very quickly while people were travelling to the Bukit Bulat area.

Results show the presence of E/W trending anomaly zones. Some of these will be faults parallel to the Mangani Graben, as readings were often taken on lines ideally oriented at right angles to the fault trend. The N/S trending vein systems such as the Rumah Sakit Vein, are oriented at quite a low angle to the lines, and will not show good anomalies.

The E/W oriented Helena Vein appears to continue to the east, as witnessed by the large anomaly (-100% filtered VLF) to the east of this vein.

The ENE/WSW fault visible on the aerial photo (Plate 11), and seen on the ground just above the A. Rumah Sakit and A. Rumah Potong road bridges, may be the origin of the -150% anomaly visible in the SE of the map. Other anomalies are not so easily matched with a known physical feature.

5.7.7 VLF over the Bukit Bulat area (Figs. 92, 102).

Anomalies related to mineralisation are often superimposed upon topographic anomalies. Specific examples of this phenomenon have already been mentioned in the discussion of known mineralisation in the Bukit Bulat area. One consequence of this problem is that unfiltered VLF is consistently negative, as a result of the topographic effect of the higher ridge to the east. Inspection of the data from the northern part of Bukit Bulat also suggests that in some parts of the area the effect of thicker conductive soils can be significant. Where the hillslopes are not as steep, such as the eastern parts of lines 320N and 500N, the quadrature data is inverted relative to the in-phase data.

The large number of anomalies present in this area means that discrimination between significant and non-significant data is difficult. Almost all SP and soil geochemistry anomalies can be matched by VLF anomalies, and many other anomalies are related to lineaments visible on the aerial photographs. The remaining anomalies may well be caused by other faults. In the Rambutan-Silver Vein area, and the Rumah Sakit Vein area there appear to be slightly fewer anomalies. This may well be due to the non-ideal line orientation, so that only larger conductors give VLF anomalies.

5.7.8 General conclusions.

Where the vein position is accurately known there was usually very little displacement between the peak of the anomaly and the vein, or the displacement was up to 10 m down-dip. In stream sections there was no overburden, so in areas with overburden the anomaly pattern might be modified. Another point of interest was the great variation of all electrical measurements with the rapid daily change in the watertable. Repetition of measurements over the same line showed that the same pattern still occurred (Fig 106), but that certain anomalies changed in amplitude. This is presumably due to disrupted conductive zones becoming more continuous when water-filled. Faults and veins clearly can be confused on the basis of VLF data, as shown by the detailed work over the Silver Vein. The effect of old mining equipment is shown by the detailed work in the A. Tambang, over the Mangani Vein.

VLF has perhaps proved one of the less valuable of the methods tried at Mangani. In some cases good correlation is obtained with other data, but careful examination of the anomalies is necessary to find boundary effects and topographic effects before other effects can be detected. Another problem is the lack of discrimination between smaller mineralised faults and mineralisation of significant dimensions.

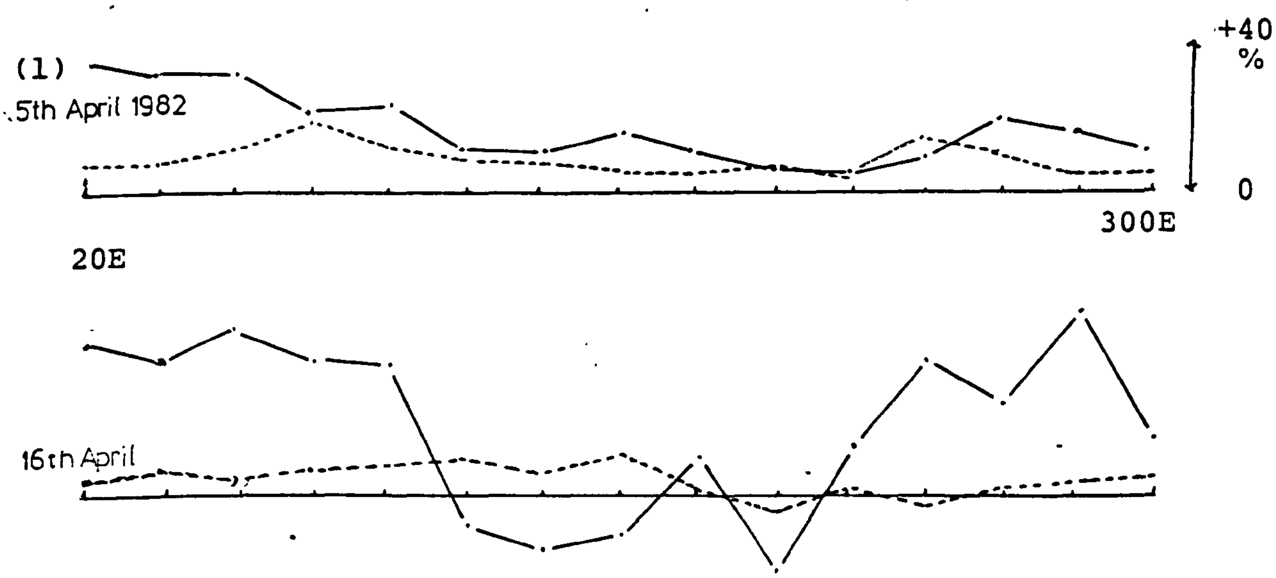
Almost all of the quadrature data seems to be

Figure 106.

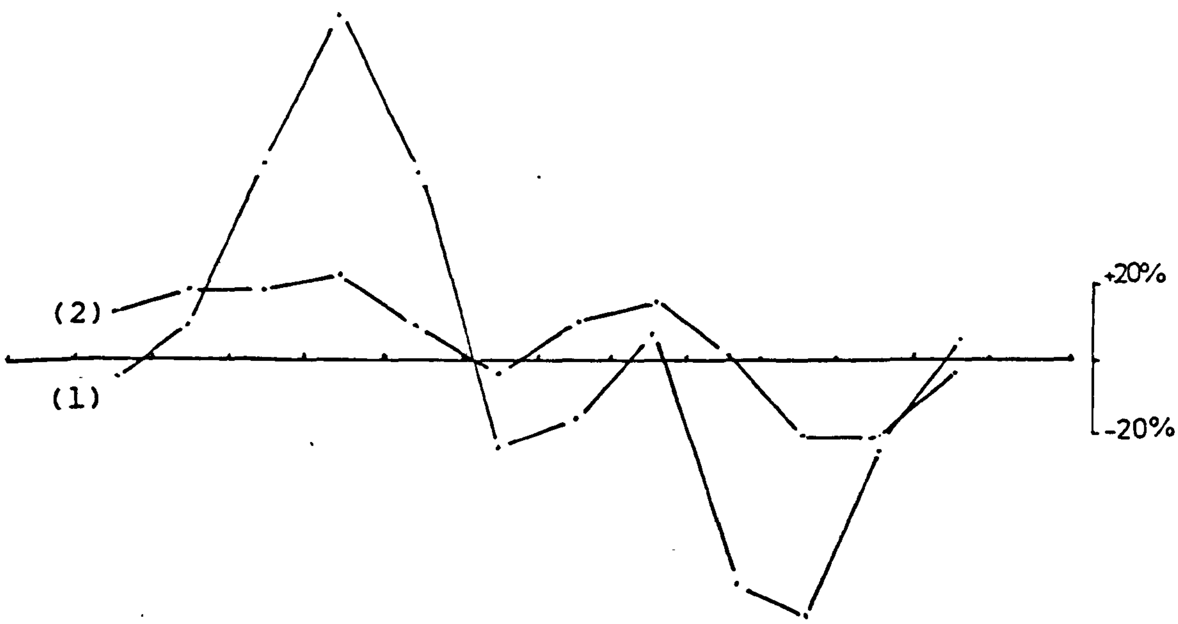
COMPARISON OF VLF DATA REPEATED OVER THE SAME LINE.

500N 20E TO 500N 300E

RAW DATA



FRAZER FILTERED DATA. (WEST TO EAST)



meaningless near known veins, which is probably a combination of the effect of magnetic storms and varying overburden conductivity and thickness. Quadrature readings were also affected by the moisture content of the ground.

5.8 TURAM electromagnetic survey

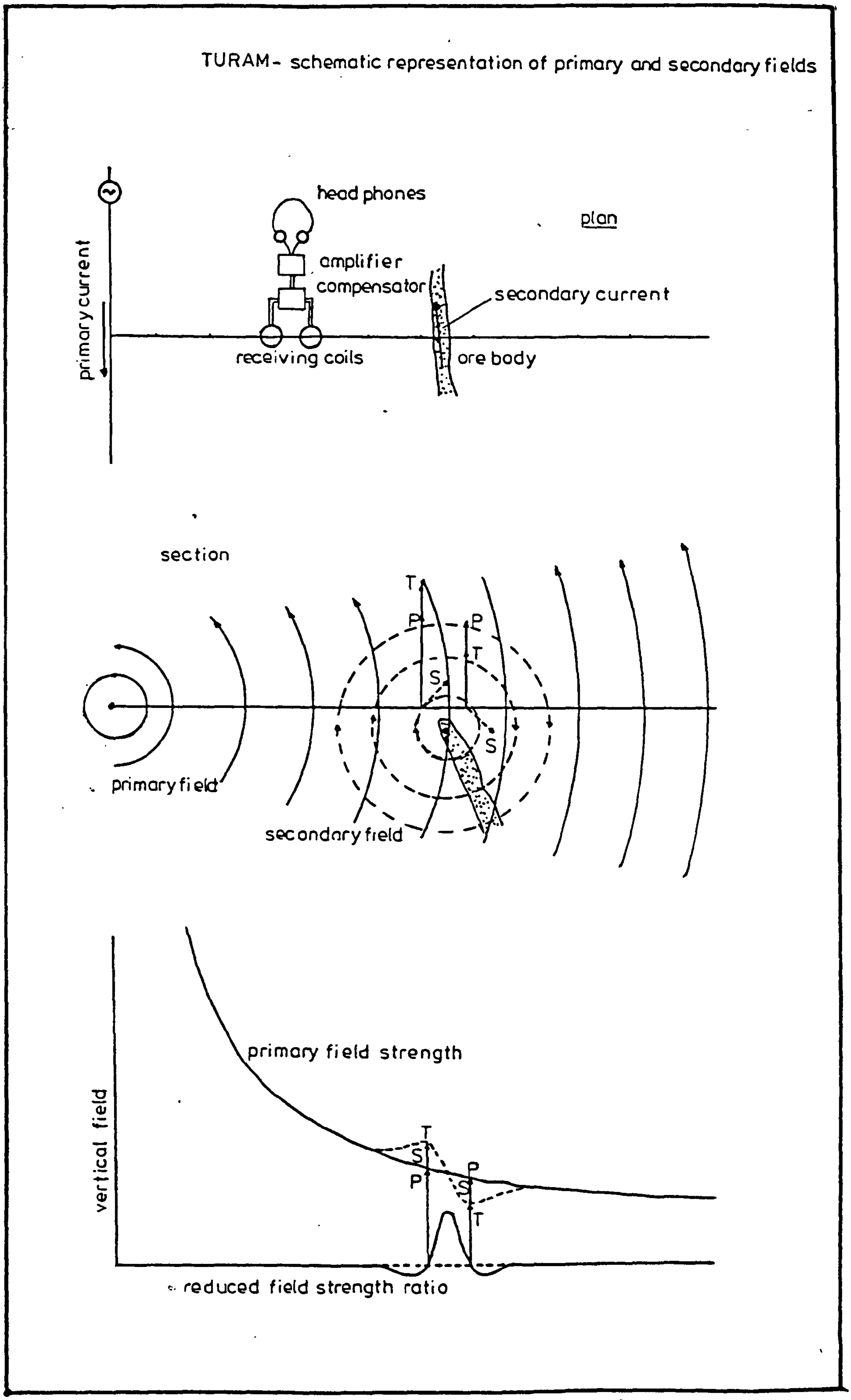
5.8.1 Theoretical basis to the TURAM method.

Like all other electomagnetic methods a primary magnetic field is applied, and the secondary magnetic field measured. With the TURAM method the primary field is generated in a long grounded wire, a large wire rectangle or a square, by an alternating current fed in by a generator. Sometimes several different frequencies are used to help discriminate between conductivity and depth of conductor, and conductive over-burden effects. The receiver unit consists of two identical horizontal coils joined by a cable. Traverses are made with fixed spacing along lines perpendicular to the long sides of a rectangular loop. The secondary field is measured as the gradient of the vertical magnetic component (amplitude ratio, or field strength ratio). The other component measured is the phase difference. Measurements are made at each station, the resulting data relating to the mid point between the two stations. If no conductor is present the phase difference will be zero, and the field strength ratio (FR) e_1/e_2 decreases with distance from the transmitter wire. The FR at each station is multiplied by the ratio of the distance from the wire to the far and near coils, producing a constant FR of 1 for readings over unmineralised terrain.

When a conducting body is present, the primary magnetic field will induce eddy currents to flow in the conductor, which causes a secondary magnetic field. The primary and secondary magnetic fields will then be measured together. The survey configuration and schematic representation of the primary and secondary magnetic fields are illustrated in Fig. 107.

5.8.2 Field procedures.

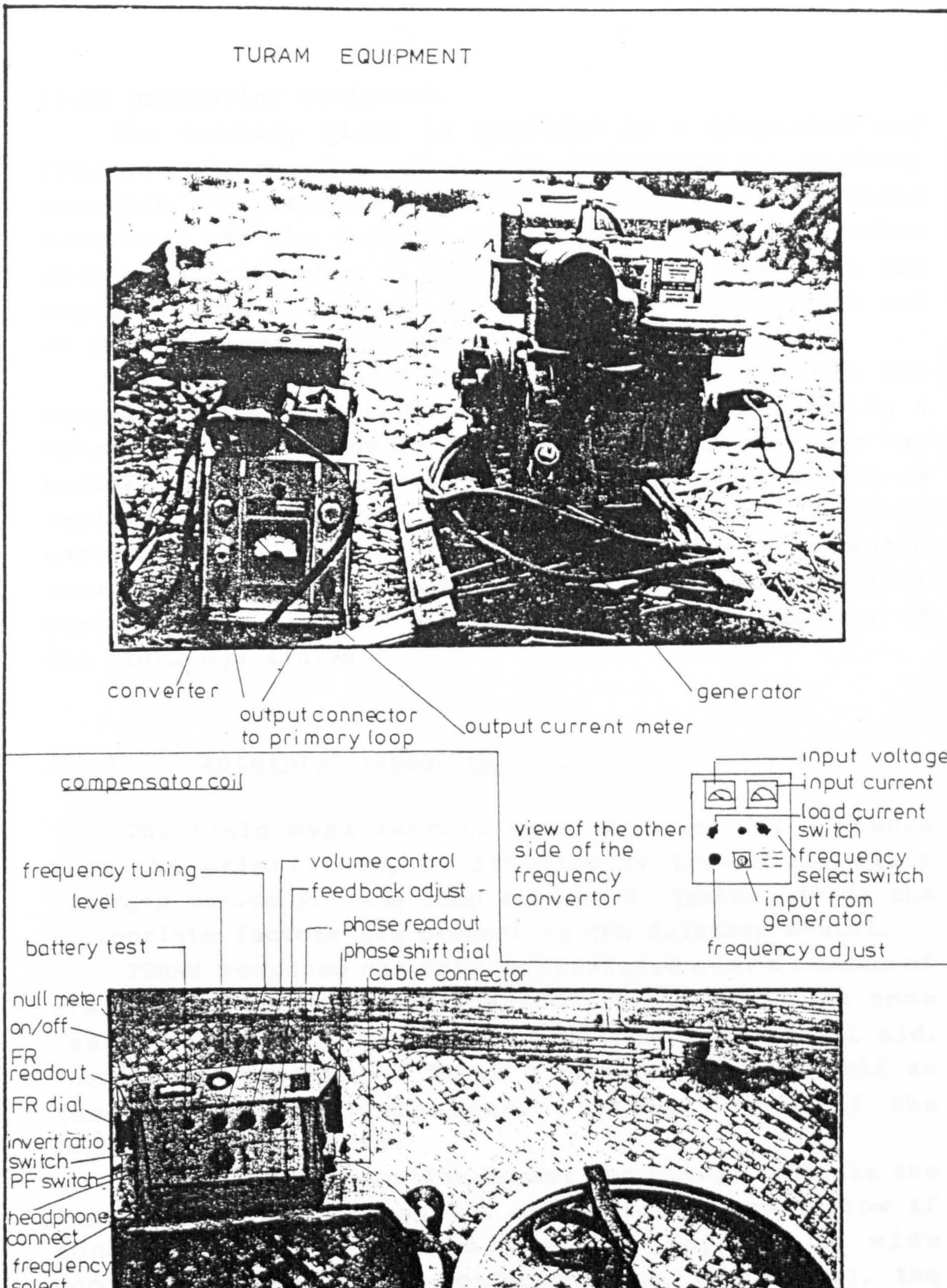
The TURAM electromagnetic method was used in the Rambutan/Silver Vein area, and the Bukit Bulat area. In both cases a large rectangular loop of thick copper wire



after Scintrex manual

was used to provide the primary magnetic field. The equipment used was the Scintrex SE-71 (Fig. 108). The equipment had not been used for a long time, so we first investigated the calibration in an area containing no conductors. The calibration was found to be highly inaccurate, and was adjusted so that the reading was zero phase difference, and the field strength ratio was one.

In the Rambutan/Silver Vein area the wire loop was rectangular, 400m by 300m. The long side of the loop was at right angles to the lines, passing through A13 and B13, and beyond the end of line A. This loop size was chosen as a length of 300m for the short side of the loop would provide adequate field strength right up to A and B1. In the Bukit Bulat area the loop size used was 240m by 320m. Care was taken to place the wire for the loop in the trees, so as to avoid grounding the current. Near the loop the field strength gradient is high, so extra care was taken in the alignment of the receiving coil, and no readings taken on either side of the loop. Readings were taken at three different frequencies (200,400,800Hz). This caused some of the biggest problems of the survey, as the radios were sometimes not effective over a range of more than 100m, and the person operating the generator had difficulty knowing when to change frequency. The thick tree growth meant that voices were also only heard over a short distance. Readings are actually made by holding the two coils exactly horizontal at two adjacent stations. Spirit levels are present on both coils. Both coils are switched to the appropriate frequency. The coils are then tuned to that frequency with a tuning control. A meter shows a maximum deflection when the coil is tuned. The signal can also be heard in headphones, which have an associated volume control. The feedback control is set at half level. A primary field (PF) switch is available to help the tuning process. This increases the unbalance voltage, so that the exact pitch of the primary field is more audible. Compensation is not possible unless the PF switch is in the normal position. When the instrument is tuned, the reading is taken by electronically compensating the phase and FR components. The two dials are turned until a minimum deflection was seen on the meter and no signal was heard. Fig. 108 shows both the receiving and


TURAM EQUIPMENT
converter
output connector
to primary loop
output current meter
generator
compensator coil
input voltage
input current
load current
switch
frequency
select switch
input from
generator
frequency adjust
view of the other
side of the
frequency
convertor
frequency tuning
level
battery test
volume control
feedback adjust
phase readout
phase shift dial
cable connector
null meter
on/off
FR
readout
FR dial
invert ratio
switch
PF switch
headphone
connect
frequency
select
level
frequency
selector
assistant's coil
cable connector
(to compensator coil)

field generating equipment.

The primary field is produced by a generator and frequency converter. When the generator is running smoothly the frequency switch is set to the desired frequency and the voltage set at the appropriate value with a potentiometer. A meter reading indicates that the input voltage is present. An input current switch is set so that this reading is about 10 amp.

Each morning the first task was to check that the loop was still intact. Once the loop had been broken by a large tree falling down. On several occasions the loop was broken, and the local people blamed large animals such as tapirs. When the loop was broken the break could be anywhere in a wire up to 800m. Much time was wasted searching for cable breaks, and only a small amount of work was done in the Bukit Bulat area, before our time in the field was finished.

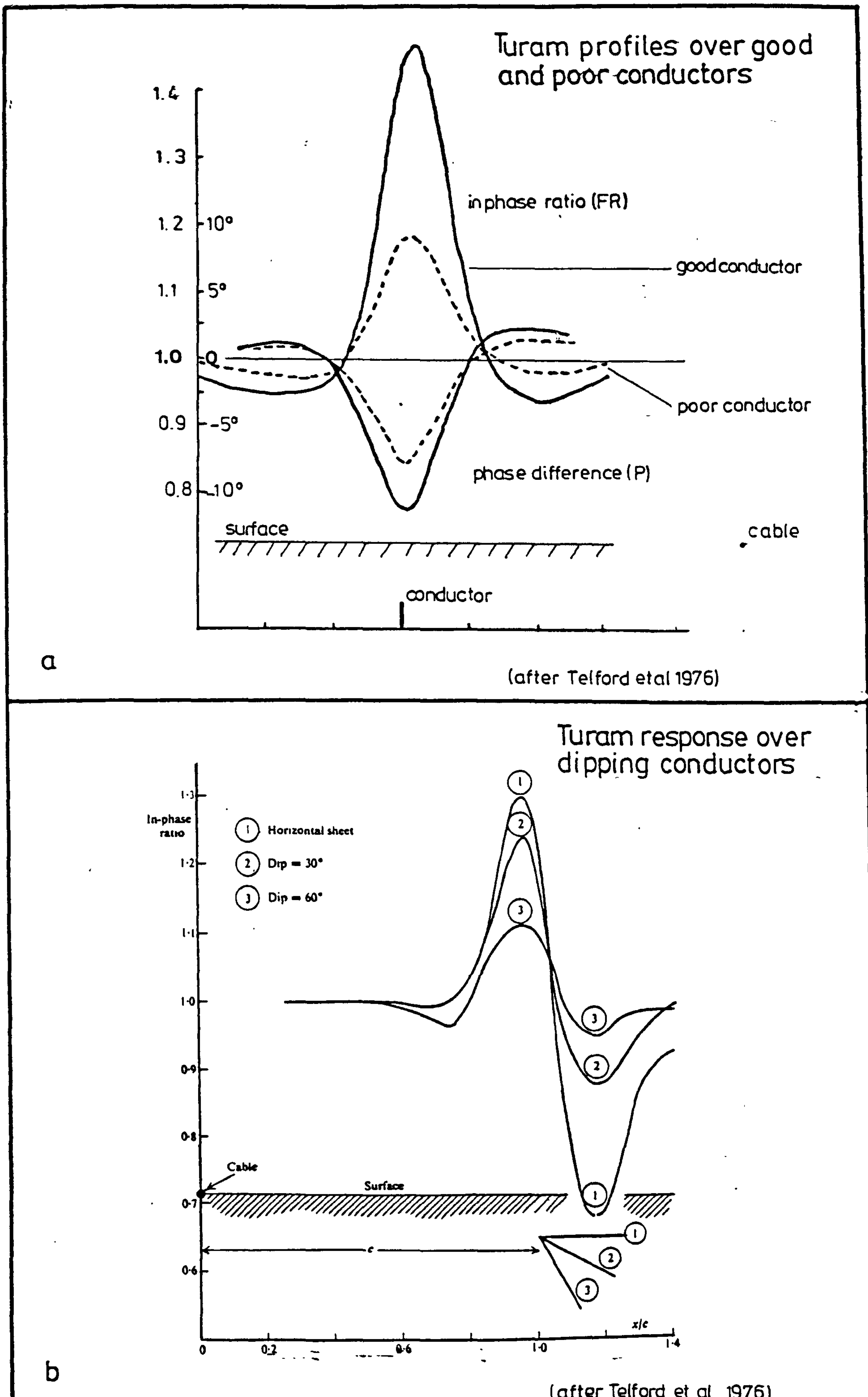
5.8.3 Interpretational theory.

The field measurements were adjusted for distance from the primary loop by dividing by the normal field strength ratios for the loop size used. Tables giving the appropriate factors are present in the Scintrex manual.

TURAM response can only be predicted over a number of simple conductor shapes (Telford et al. 1978). In some cases scale models are used as an interpretational aid. Anomalies produced over known mineralisation, as well as theoretical considerations, are the origin of the following observations.

Where field distortion occurs the curves indicate the location and depth of burial of the main current flow if conductors are thin and steeply dipping. In wide conductors or horizontal conductors (e.g. overburden), the current is more widely dispersed, and the anomalies yield less information. Generally the current axis is located below the the maximum FR deflection or the maximum negative phase shift. A good conductor is characterised by a large FR anomaly with little phase shift The field beyond a very good conductor can be too weak for reception of the signal, due to the shielding effect of the

Figure 109


Turam profiles over good and poor conductors
1.4
1.3
1.2
1.1
1.0
0.9
0.8
10°
5°
0
-5°
-10°
inphase ratio (FR)
good conductor
poor conductor
phase difference (P)
surface
cable
conductor
a
(after Telford et al 1976)
Turam response over dipping conductors
In-phase ratio
1·3
1·2
1·1
1·0
0·9
0·8
0·7
0·6
1 Horizontal sheet
2 Dip = 30°
3 Dip = 60°
Cable
Surface
c
x/c
0
0·2
0·6
1·0
1·4
b
(after Telford et al 1976)

conductor. A poor conductor affects the phase component rather than the field strength ratio. Figure 109a shows the typical TURAM anomaly over a narrow steep conductor, and the effect of conductivity.

Conductive overburden can mask even good conductors, due to the strong field distortion.

One of the main reasons for measuring traverses using different frequencies is that at lower frequencies conductive overburden will not cause such large anomalies, though at high frequencies the magnetic field produced in a conductor will be stronger. Addition of a strong secondary magnetic field to the field produced in a magnetic body will not cause a significant effect at high frequencies, but at low frequencies anomalies are distorted, producing an inflection point rather than an FR maximum. TURAM response at different frequencies is also useful in distinguishing between a good conductor at some depth, and a shallow, poor conductor, since at lower frequencies there is a greater depth penetration of the primary field.

If thin conductors are dipping, anomalies will be displaced downdip, with the upper edge of the sheet located beneath the FR minimum. The direction of dip can be deduced from the location of the FR maximum. If the FR maximum is located nearer to the cable than the minimum, then the dip is away from the cable (Fig. 109b). If the low frequency curve is displaced relative to the high frequency curve, this is displaced downdip.

If accurate results are required the conductivity-thickness product can be found from calculating inphase and out of phase components, taking into account the frequency used and strike length of the conductor (Parasnis 1973). Since the TURAM ratios can be calculated from observations of field intensity gained with the Sunberg method, and vice versa, these methods are equivalent.

Terrain corrections can be made if the transmitting cable is considered to consist of a number of straight line segments.

5.8.1 TURAM investigation of the Rambutan/Silver Vein area (Figures 110-112).

Figure 5 shows the location of these lines. No good examples of simple anomalies due to sheet conductors are present. The veins in this area are known to consist of material which is not very conductive, so this is not surprising. The Mangani Graben edge is likely to be the origin of an anomaly at A17-A18. The anomaly at A26 may well be due to another cast iron waterpipe, as one of the old mine roads lies just to the north. On line B anomalies are present at B14-15 and B3.

At higher frequencies there are more anomalies, which are likely to be due to changes in thickness of the overburden. In a number of cases field distortion seems to be due to topographic effects, as can be seen in Figures 110-112.

5.8.5 TURAM in the Bukit Bulat area. (Figures 113-115).

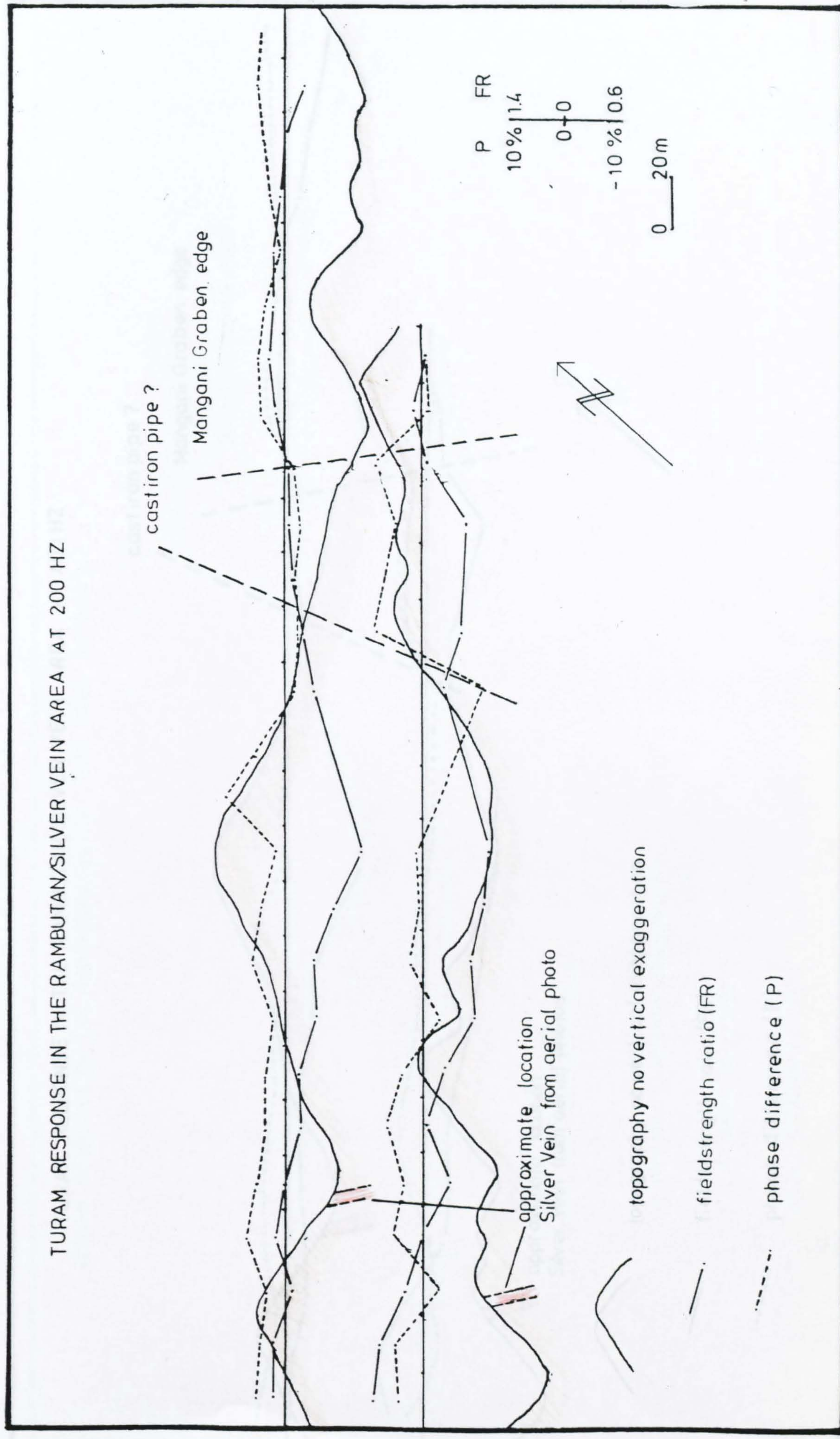
The location of the lines is shown in Figure 5. Only a small amount of work was done in this area due to problems with cable breaks, and communication difficulties between the generator operator and the receiving coil operators.

Table XII shows the location of the TURAM anomalies, and related S.P VLF and geochemical anomalies. Quite good correspondence can be seen between the location of TURAM anomalies and geochemical, S.P, and VLF anomalies, showing that realistic results are being obtained. However geochemical and S.P anomalies are much clearer, and were obtained with less effort.

5.8.6 Conclusions relating to the use of TURAM at the Mangani.

In many cases negative phase shifts are associated with geochemical anomalies, lineaments on aerial photographs or S.P or VLF anomalies. The number of

Figure 110. TURAM response over the Rambutan-Silver Vein area at 200 Hz.



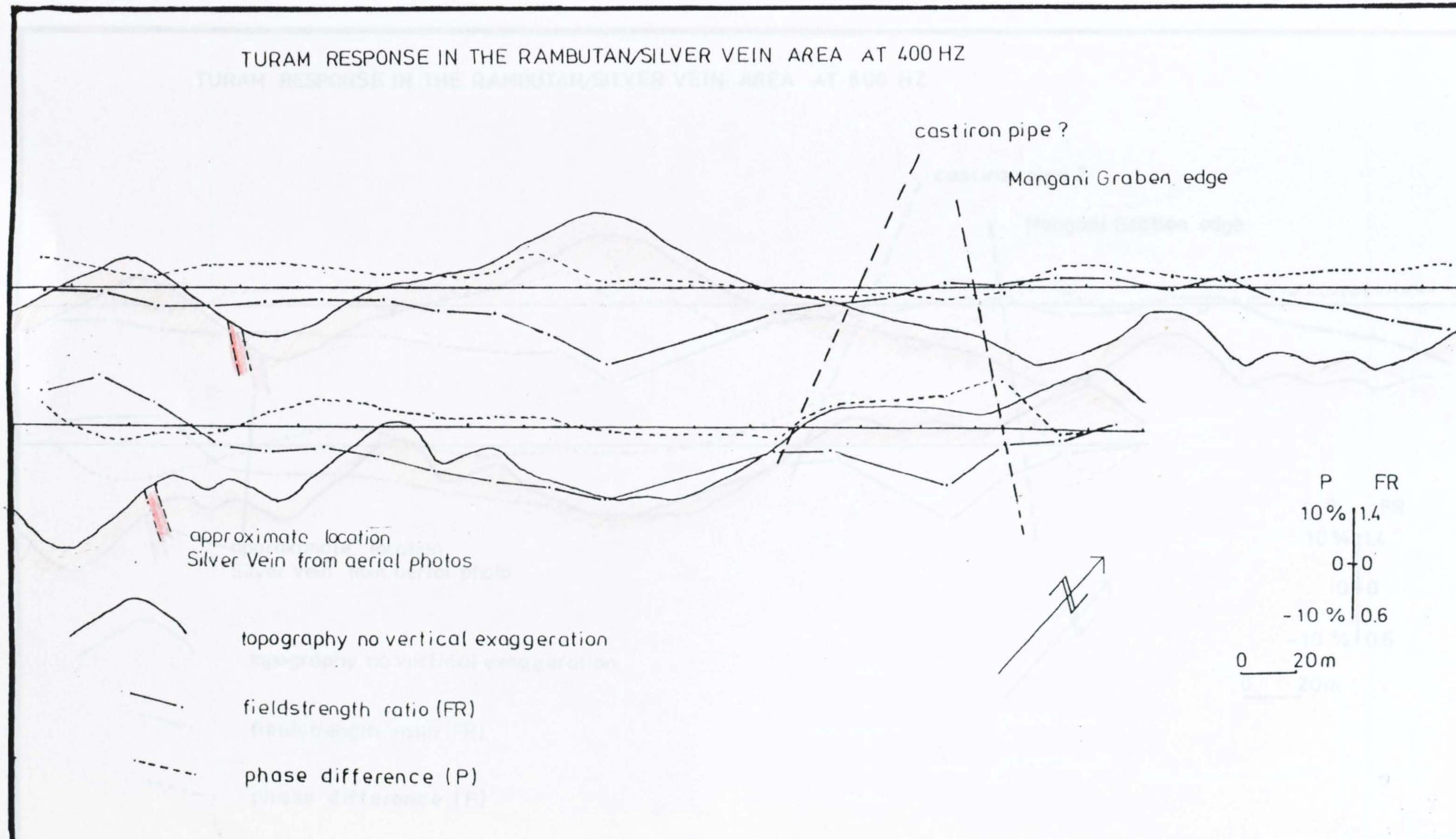


Figure 111. TURAM response over the Rambutan-Silver Vein area at 400 Hz.

Figure 112. TURAM response over the Rambutan-Silver Vein area at 800 Hz.

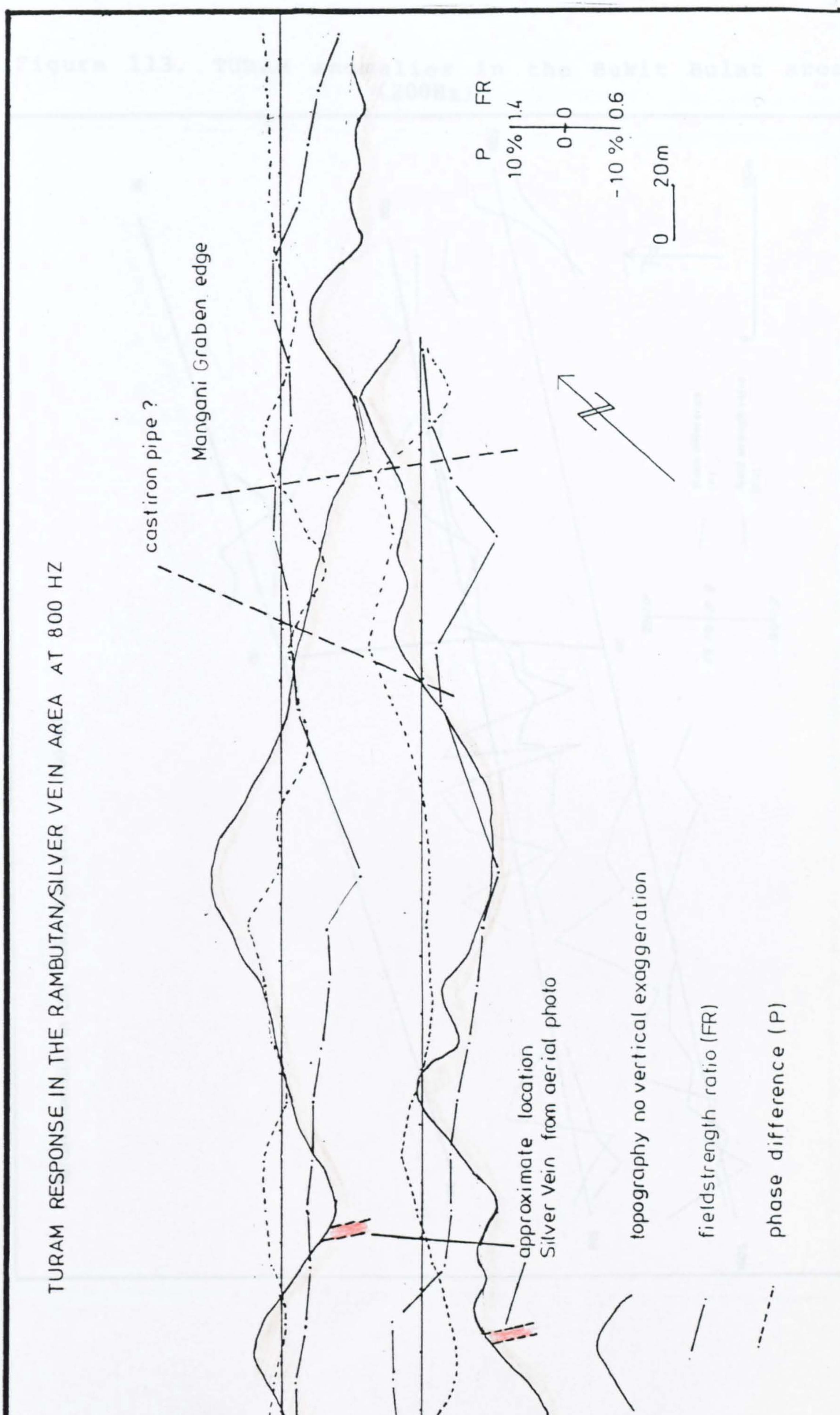


Figure 113. TURAM anomalies in the Bukit Bulat area (200Hz)

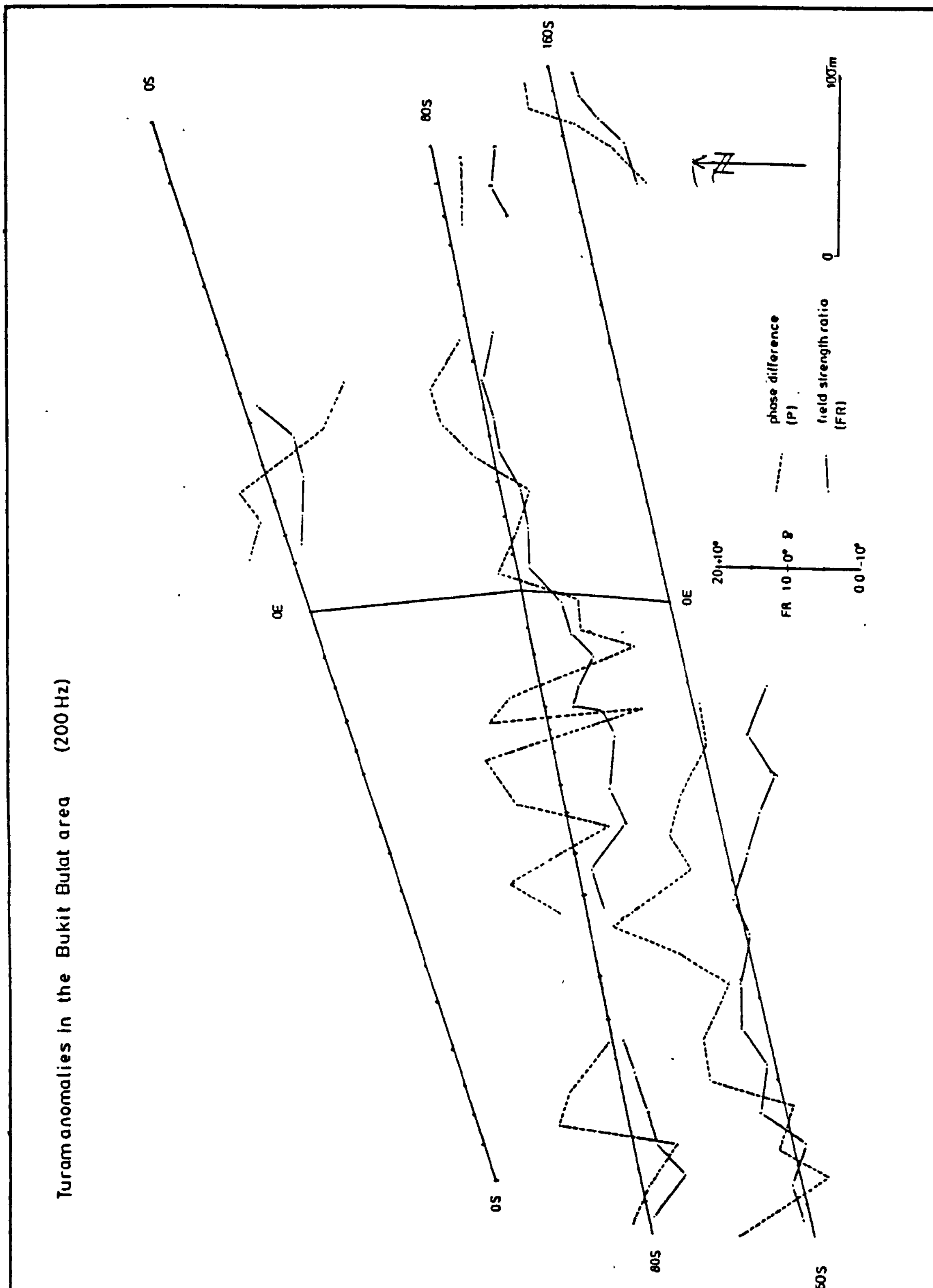


Figure 114. TURAM anomalies in the Bukit Bulat area (400Hz)

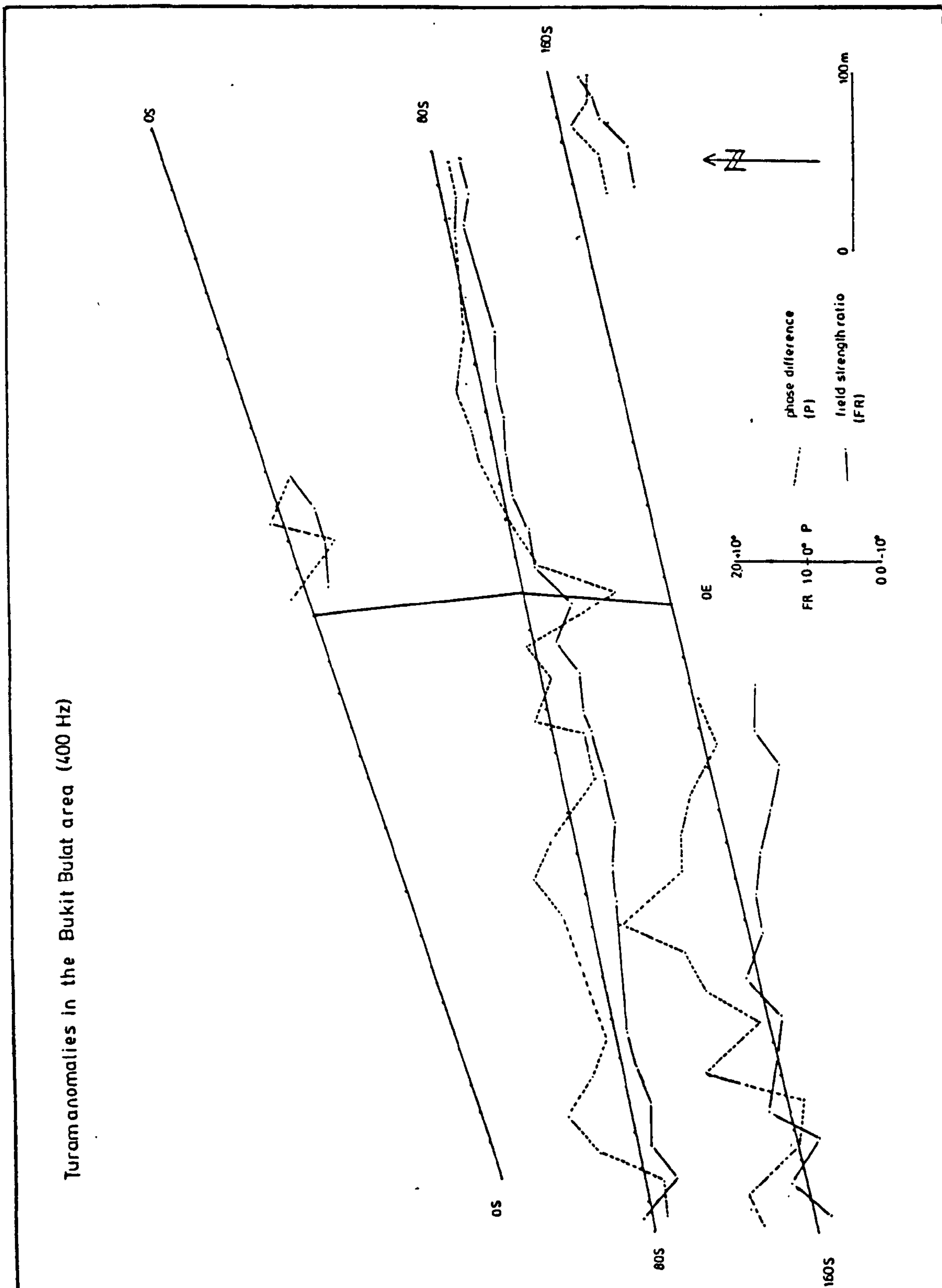
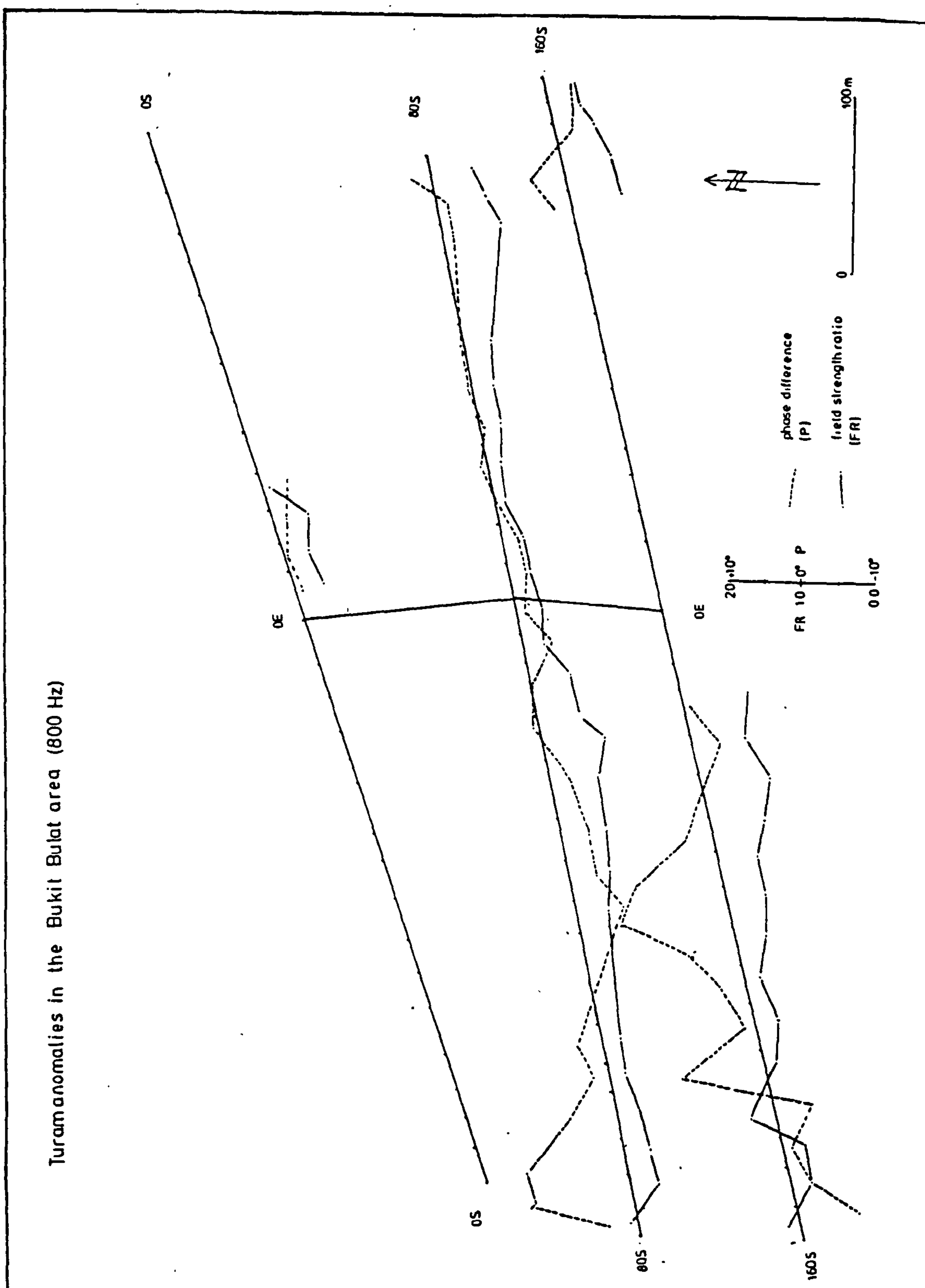


Figure 115. TURAM anomalies in the Bukit Bulat area (800Hz)



anomalies is less than with VLF, though lineaments with no significant associated geochemical anomalies also produce TURAM anomalies. In some cases overburden seemed to be causing anomalies, even at lower frequencies, while known veins in the Rambutan/Silver Vein area did not produce good anomalies.

Although results were significant, this method was not economic in terms of the time and effort, as well as transport and manpower costs. In less forrested, flatter terrain such a method might be viable.

Table XII. Comparison of TURAM anomalies in the Bukit Bulat area with anomalies found using other methods.

	800Hz	400Hz	200Hz	S P	Geochem	VLF
160s	290W *		*	*	*	
	250W *	*	*	*	*	
	190W *	200W *	180W *			180W *
	70W **	70W **	70W **			*
	290E**	**		**		*
80S		370W *				
			340W	*		
			170W **			*
		140W ***				
			100W ***	***		
		50W ***				
			40W ***			
	30W ***					
						10E *
0S		30E *				
			50E*	(40E break in slope)		
	70E *	*				
			80E *			
						100E

Stars in each column indicate the relative importance of an anomaly. The station location is shown for each different anomaly location, and where anomalies found with different methods are probably due to the same conductor, but are displaced relative to each other.

5.9 Magnetic method.

5.9.1 Previous magnetic work.

The Indonesian Geological Survey (Harsono et al. 1978) investigated the area shown in Figure 16 with both a total magnetic field magnetometer (proton precession), and a vertical field magnetometer (fluxgate). A summary of their results is shown in Figure 17.

It is difficult to know whether the positive total field anomaly near the Mangani Vein is due to the mineralisation, or due to the abundant abandoned steel cables and old machinery near that area.

There is no obvious change in the magnetic field over the Rumah Sakit Vein.

A number of quite large anomalies (+600 gammas) occur in areas with no known mineralisation, and in areas with no remains of mining equipment. These are marked on Figure 16. These may be caused by basic rocks at depth, but in most cases the surface outcrop consists of volcanics, sometimes pyritised.

The vertical field map shows a very irregular contour pattern over the Mangani Vein, and over a zone extending to the SSE from that point, and possibly delineates the mineralisation more clearly. Vertical field anomalies are marked on Figure 16.

The Indonesian Geological Survey work suggests that the magnetic method (both total and vertical field) does not delineate the known mineralisation very effectively. However the method may be of use in elucidating the geology in unexposed areas.

5.9.2 Basis of the method.

At the time of formation of a rock, any magnetic particles will have been oriented along the prevailing magnetic field. This will occur either by formation of the mineral in that orientation, or by rotation of grains into that position during deposition. Measurement of the magnetic field at any one place will record the effect of the earth's magnetic field, and the effect of the varying proportions of magnetic minerals in near surface rocks.

Measurement of the magnetic field can be valuable in locating rocks with a high percentage of magnetic minerals, such as basic igneous rocks. Some of the Mangani veins contain the magnetic form of the mineral pyrrhotite, and should be detectable as linear anomalies. Basic dykes would form similar anomalies, so other methods are necessary in order to distinguish dykes and veins.

A number of types of magnetometer are available for measuring the earth's magnetic field. Of the more modern types, the fluxgate magnetometer measures any desired component of the magnetic field, while the proton precession magnetometer measures the total field. The second type was used at Mangani. The proton precession magnetometer works by polarising protons (hydrogen nuclei), in a direction approximately normal to the magnetic field. This is done by passing a direct current through a solenoid wound around the bottle containing the hydrogen rich fluid (e.g. paraffin). When the polarising field is stopped abruptly the protons precess about the direction of the field in a way analogous to a spinning top precessing around the earth's gravity field. The proton precesses at an angular velocity proportional to the magnetic field strength. A transient voltage, modulated by the precession frequency, builds up, and is detected by a second coil. The gyromagnetic ratio of the proton is accurately known, so the magnetic field can be calculated. Using this method the magnetic field can be measured with a sensitivity of $\pm$ 1 gamma.

5.9.3 Field procedure.

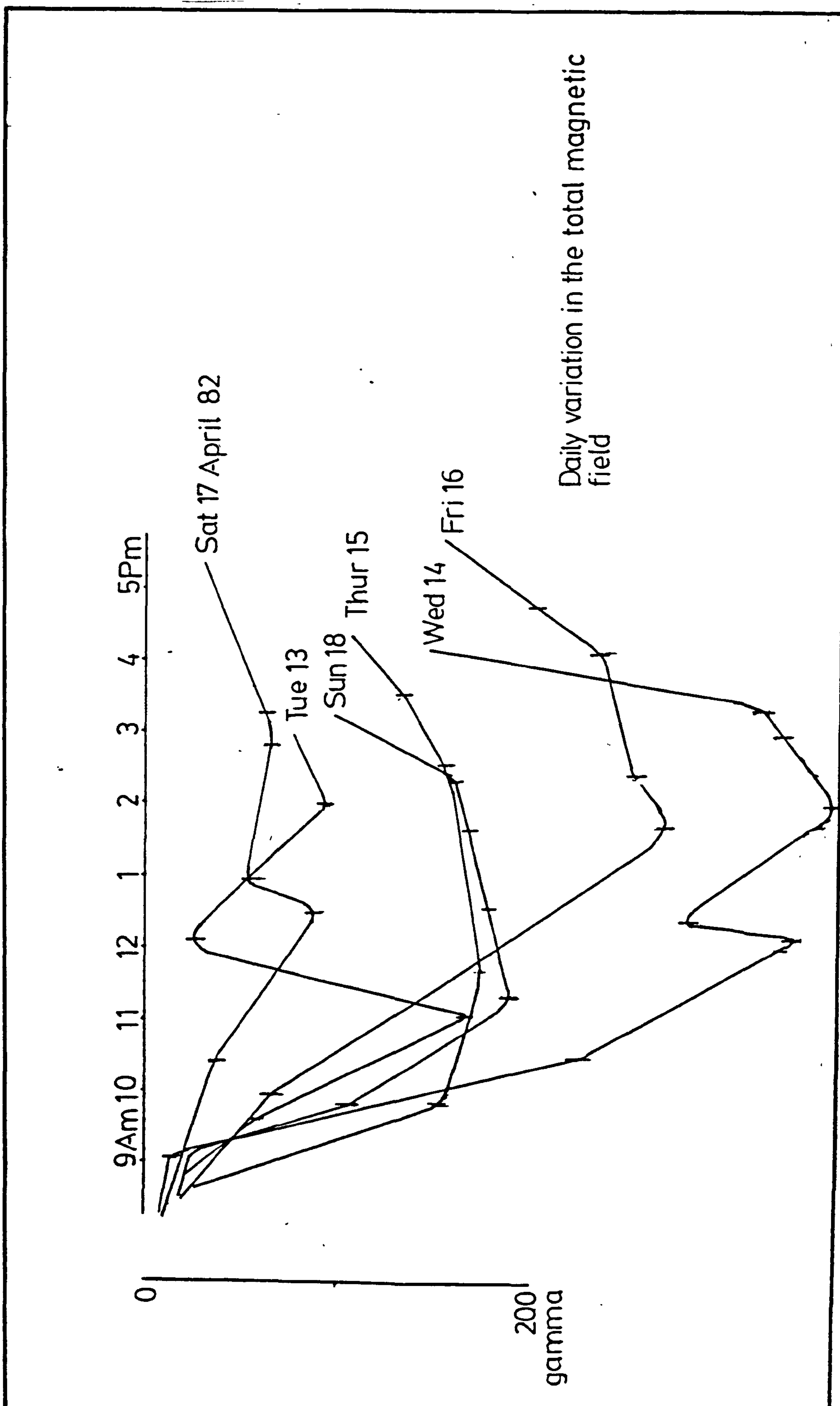
At Mangani a Geometrics proton precession magnetometer was used. For really accurate work the magnetic field sensor is usually held on a long aluminium pole to avoid measuring only the effect of the ground near the sensor, and the magnetism of the magnetometer itself. At Mangani the sensor had to be carried in a backpack to avoid getting the long pole tangled in creepers. The magnetometer was carried in a harness in front of the same person, so that the effect of the magnetic components in the magnetometer such as batteries was constant. People involved in the magnetic survey had to be careful to avoid carrying magnetic objects such as bush knives. The sensor was oriented in the appropriate direction while readings were being taken, by the person carrying the equipment facing north. At each location measurements were made and checked by repeating the reading, and the time, location and reading noted down.

In any one place the reading taken will vary systematically during the day due to the diurnal variation of the earth's magnetic field. For this reason readings are repeated at intervals at the same station and adjusted to allow for this change . Figure 116 shows the diurnal variation during the period of magnetic measurements at Mangani. The variation was quite large, and radio interference suggested that there was a magnetic storm. Difficulties in returning to the same spot with sufficient frequency meant that on some days correction graphs were not as accurate as might have been desired. The amount of variation in the magnetic field was large on almost all the days in which measurements were taken. Normally magnetic measurements will not be made during periods of magnetic disturbance, but as a result of equipment breakdown the magnetometer was only available for a very short period.

5.9.4 Interpretation procedure.

Interpretation is usually qualitative initially, and later if suitable distinct anomalies are present a quantitative interpretation can be made. Quantitative interpretations can be made by assuming particular dimensions for the magnetic body and calculating the anomaly produced by such a body, then comparing the measured with the calculated magnetic profiles. In mountainous terrain data should be reduced to a horizontal plane by upward continuation (Telford et al. 1976), or the magnetic field can be calculated for a particular topographic section. At Mangani no clear anomalies suitable for quantitative interpretation were present,

Figure 116. Daily variation in the total magnetic field in the Mangani area, 13-17th April, 1982.



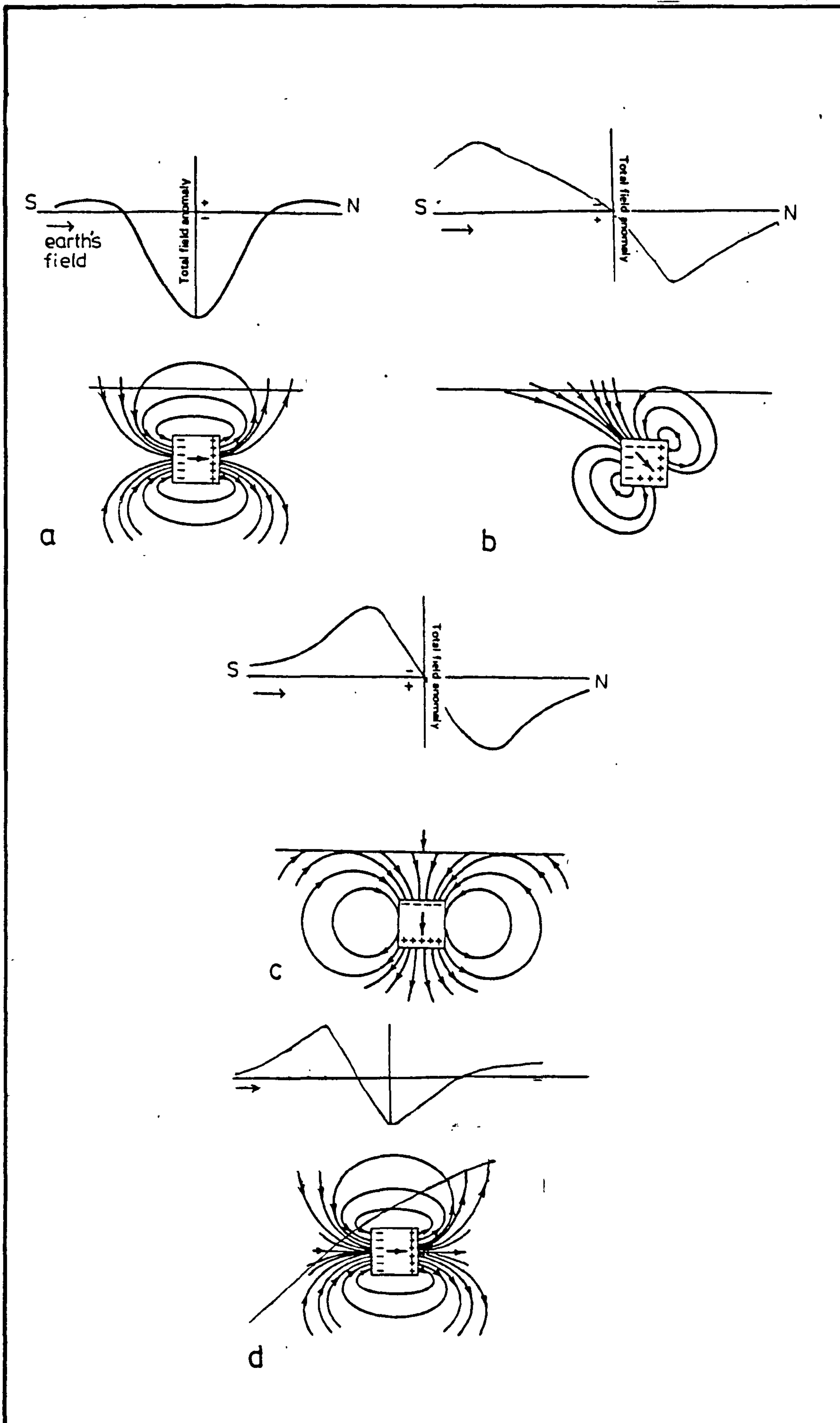
therefore interpretation was qualitative.

Mangani is situated exactly on the geographical equator, and therefore also near the magnetic equator. Though the total field has been measured, the horizontal component will be the main part of this. Most of the known veins strike NNE/SSW, but are rarely continuous, varying widely in metal content, and presumably magnetic effect. Such a body could be compared to a polarised sheet, or since the mineralisation is intermittent, the effect is likely to be similar to a series of dipoles (Telford et al., 1976).

The mineralisation at Mangani is considered to be Mio-Pliocene in age, so that the orientation of the earth's magnetic field at that time would not be significantly different from today, though possibly reversed in polarity. If an equidimensional magnetic body was magnetised in the same orientation as the present magnetic field, then the anomaly over that body would consist of a negative over the centre of the body, with small positive wings (Fig. 117a). A dyke or sheet like body would have a similar effect, but without the positive wings. If the magnetic body was initially magnetised in the reverse direction, the anomaly would be inverted, though the resultant of the remnant magnetisation and the present day induced magnetisation may result in an orientation similar to those shown in Figures 117b,c. The effect of topography is shown in Figure 117d.

Discontinuous magnetic veins oriented N-S, with an approximately horizontal inclination of the primary field, will produce a series of anomalies similar to the one illustrated in Figure 117a during a N-S traverse in flat terrain. An E-W traverse would also show such an anomaly pattern if the traverse was over the central area of the magnetic section of the vein, otherwise just a small positive anomaly would be observed. In steep terrain, an asymmetric anomaly pattern would be seen. At Mangani most traverses are oriented E-W, in order to gain sharp narrow anomalies over N-S veins when using other exploration methods, so are not ideally oriented for magnetic work. A number of N-S traverses were also made over the northern margin of the Mangani Graben (oriented ENE-WSW), and should have discovered an anomaly related to the

Figure 117. The total magnetic field produced over magnetic bodies with differing orientations.



mineralisation, but did not, suggesting that mineralisation may not be sufficiently magnetic to produce good anomalies.

5.9.5 The total magnetic field over known veins.

Unfortunately at Mangani the anomalies over known mineralisation are small, and appear to be superimposed on other anomalies. Figure 118 shows the total magnetic field over the veins outcropping in the Bukit Bulat area. The most conspicuous feature of the behaviour of the magnetic field over these NNE/SSW veins is the presence of positive gradients from west to east over the veins. Over the Reinier/Gorge/Gulley mineralised zone the magnetic field is complex, though the positive peak at 160S 280W seems to correspond to anomalies discovered with other methods.

5.9.6 The magnetic field over the Rambutan/Silver Vein area. (Fig. 119).

This area was not covered by the previous magnetic survey at Mangani (Harsono et al. 1978). Figure 119 shows that little information is gained about the mineralisation, or about the southern edge of the Mangani Graben. The magnetic low at A1 could be caused by the Rambutan Vein, which is thought to outcrop in the cliff west of this point, but the remains of a concrete ramp may also be responsible. The slight magnetic high at B10 is associated with a quite high SP gradient, and a small VLF anomaly, suggesting the presence of a mineralised dyke. The regional gradient on line A suggests that the Brani Conglomerate has a lower total magnetic field than the volcanics and other rocks in the Mangani Graben. The decrease in the magnetic field at the eastern end of line A is of unknown origin.

Figure 118. Total magnetic field profiles over the Linda, Eloise, Merah Selasa and Reinier-Gorge-Gully Veins.

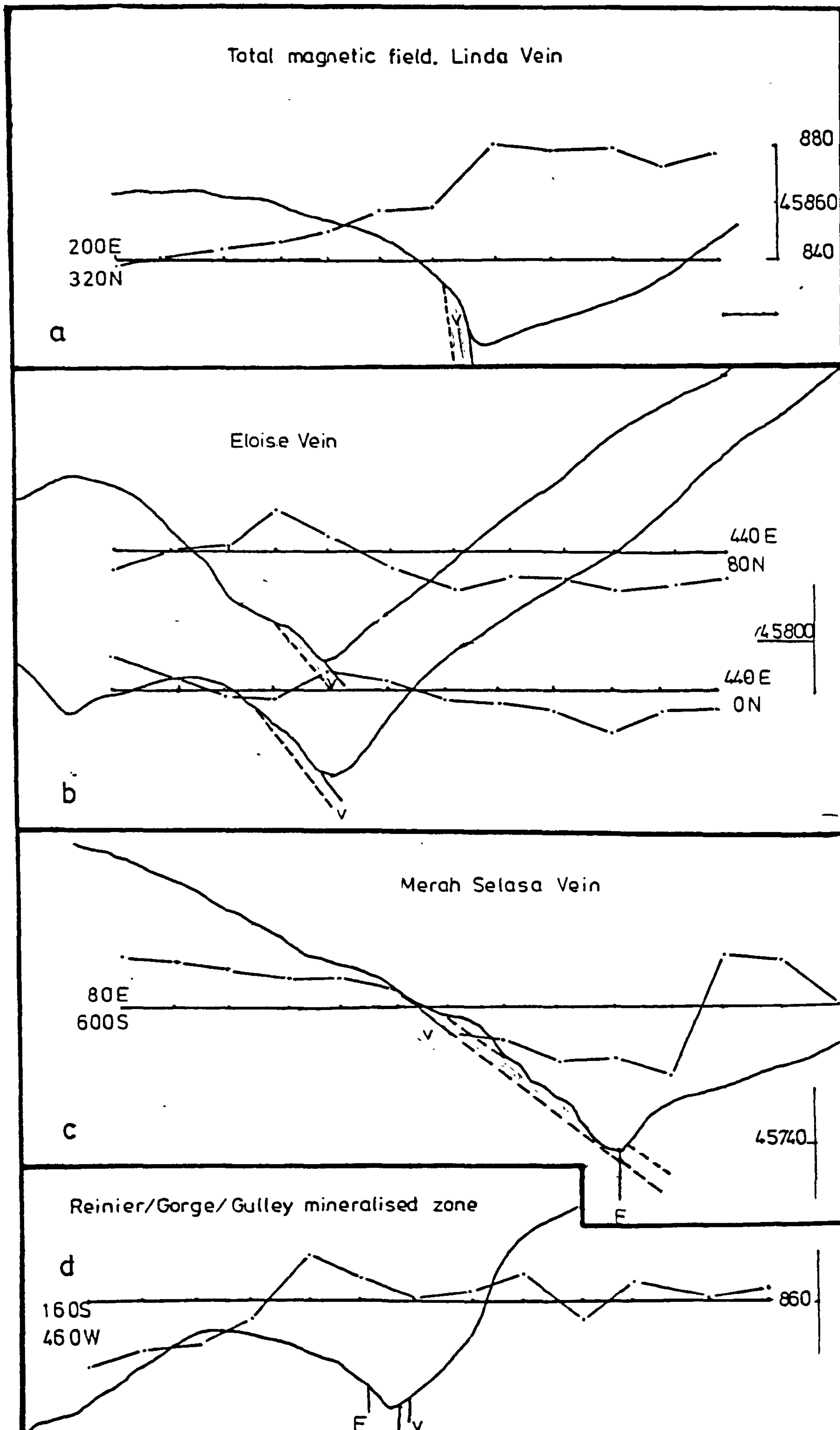
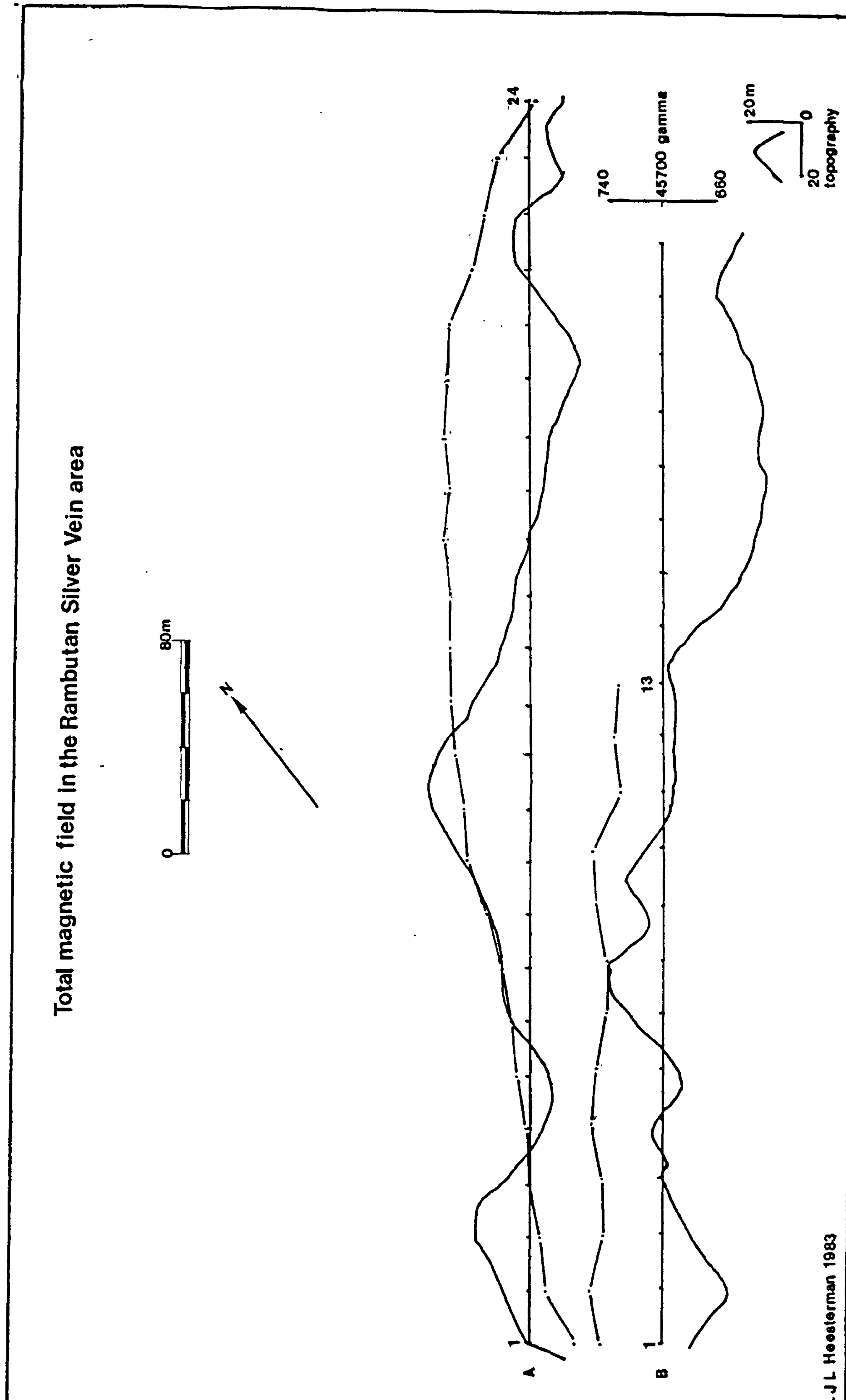


Figure 119. Total magnetic field in the Rambutan-Silver Vein area.



5.9.7 The magnetic field in the Bukit Bulat area. (Figure 120)

The broad magnetic pattern in the Bukit Bulat area seems to contain a regional gradient, with a higher field to the north and west. One factor which is not known is the extent to which lateritic soils on hill tops are thicker, and might produce magnetic anomalies.

Magnetic variations of 20-40 gammas appear to be associated with known mineralisation. As well as variations over the known veins, variations of this order are found at:-

600S 0E-20E,
500s 80-60W,
400S 380-360W, 220-200W, 200-180W, 120-100W, 100-80W,
240S 20W-0E,
160S 400-380W
80S 200-180W, 180-160W, 160-140W, 120-100W,
80N 60-40W, 40-20W, 20W-0E,
160N 320-300W
500N 300-280W, 140-160E, 480-500E.

Figure 121 shows the magnetic field on a N-S traverse over the northern margin of the Mangani Graben. There is no clear anomaly, suggesting that despite the presence of pyrrhotite in clasts in a fault breccia presumably derived from this area, the mineralisation in this location is not very magnetic.

5.9.8 Discussion of magnetic work done in the Mangani area.

Generally the magnetic work done in this area has produced few significant results, suggesting that though magnetic minerals are visible in vein specimens, they do not occur in amounts large enough to give anomalies that are distinguishable from background variations due to magnetic minerals in soils and host rocks. There also seems to be little variation in the magnetic properties of the different rock types, as the northern margin of the Mangani Graben seems not to be associated with any

Figure 120. The total magnetic field in the Bukit Bulat area.

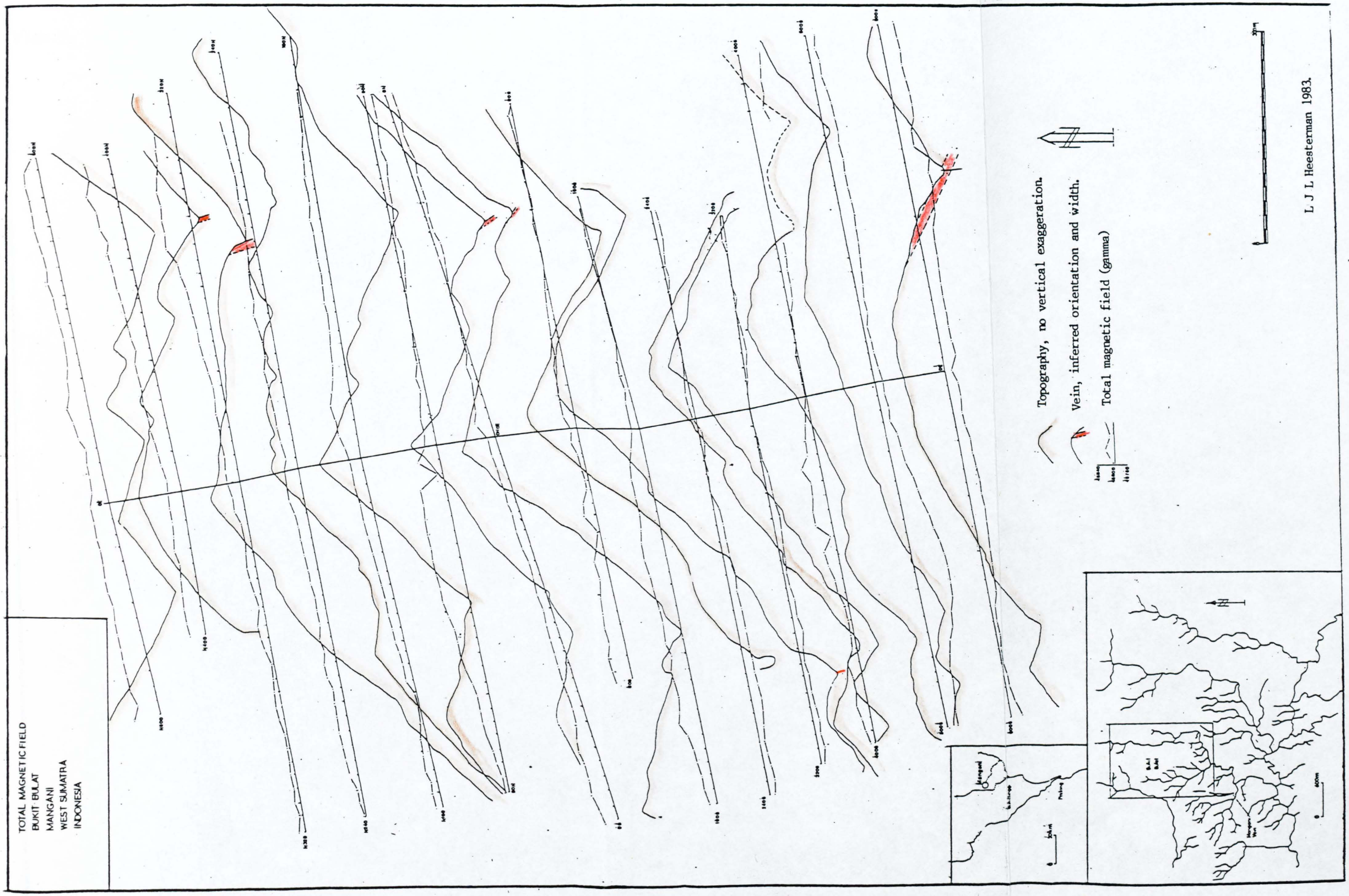
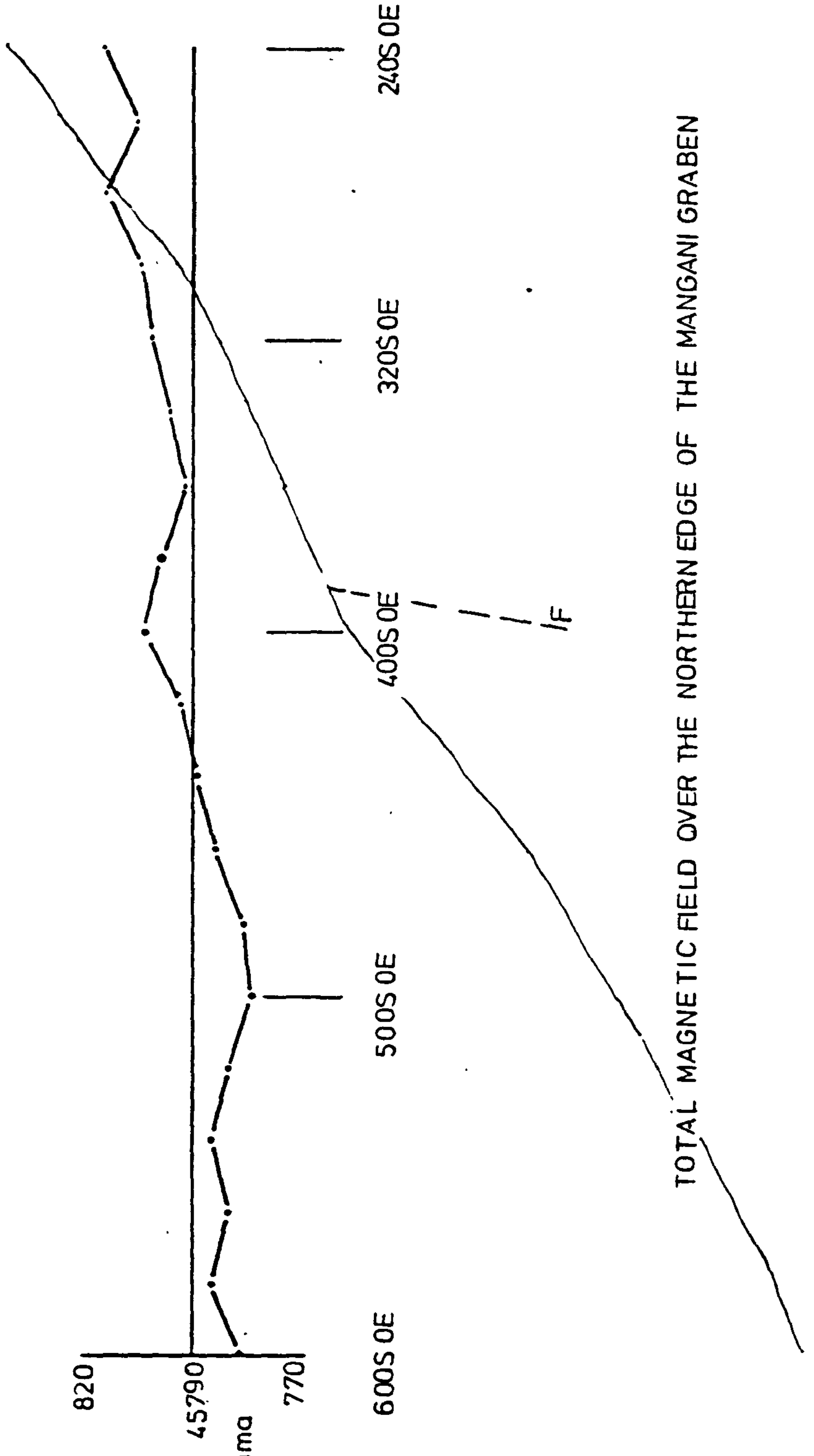


Figure 121. The total magnetic field over the northern edge of the Mangani Graben.



consistent anomaly. The presence of a peridotite cobble on one of the roads to the south of the Bukit Bulat area suggested there might be an ultrabasic body in the area, a suggestion supported the regional geochemical anomaly for cobalt and nickel found by IGS. A number of small dolerite bodies also outcrop in streams in this area. Magnetic work done in the Bukit Bulat area suggests that if an ultrabasic body is present in the Mangani region, then it is not in the Bukit Bulat area. Similarly the dolerites in the region seem to have little magnetic effect.

5.10.0 Conclusions relating to the investigation of mineralisation in the Bukit Bulat area.

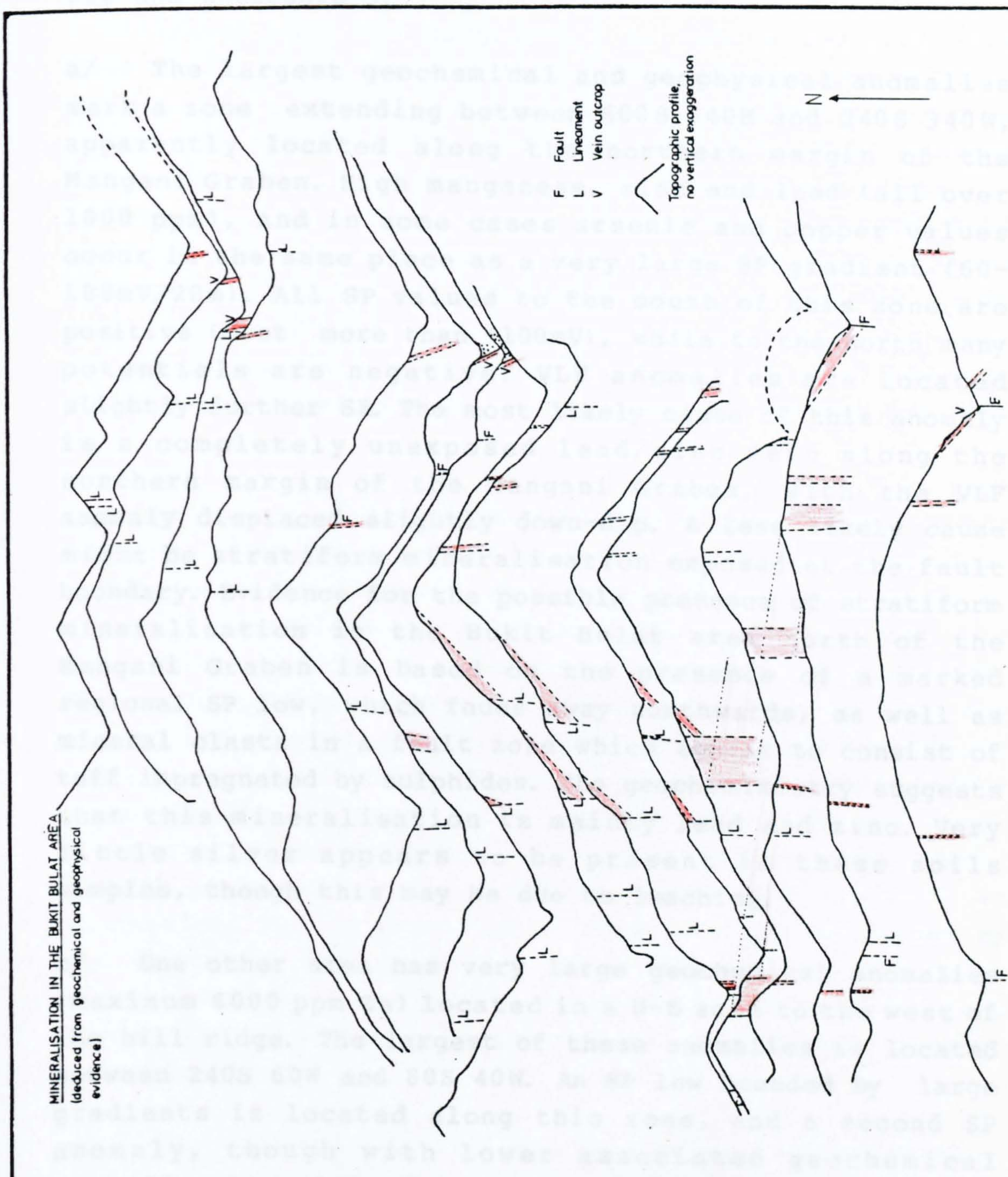
Known veins in the Bukit Bulat area seem to be best delineated by large SP gradients on the hanging wall side, as well as the presence of large lead, zinc and manganese concentrations. Soil sampling and SP work are the methods recommended for investigation of any similar mineralisation in a similar geographic setting, these methods also being the easiest and most rapid of the methods tried at Mangani. Work by the Indonesian Geological Survey (Harsono et al 1978) suggests that some of the veins in the southern part of the Mangani area (Rumah Sakit and Rumput Pait Veins) are not associated with significant SP anomalies, and in some cases with only limited geochemical anomalies. Such veins can only be identified in outcrop, and for this reason each stream, even very small ones, must be mapped in detail to discover such veins.

VLF anomalies are produced over known veins, but also over many other features, including faults with only minor mineralisation. Over SP anomalies VLF can be of value in identifying the direction of dip.

TURAM produces anomalies over some of the known mineralisation, but the time and effort needed to collect the data, as well as the difficulty in making quantitative interpretations in mountainous terrain suggest that this method is perhaps unsuitable for the Mangani area.

Magnetic anomalies produced by the mineralisation in the Bukit Bulat area are not sufficiently well defined to delineate the mineralisation. Work by the Indonesian Geological Survey (Harsono et al. 1978) suggests that this method is also not suitable for identifying known veins in the southern part of the Mangani area, though there some large anomalies were found, possibly related to basic rocks at depth.

Figure 122. Topographic profiles across the Bukit Bulat area, showing mineral veins considered to be present as a result of geophysical and geochemical investigation in the area.



5.10.1 Conclusions about the distribution of mineralisation in the Bukit Bulat area.

All areas where geophysical and geochemical data suggest that mineralisation occurs are marked on Figure 122 and Enclosure 5.

a/ The largest geochemical and geophysical anomalies mark a zone extending between 600S 240E and 240S 340W, apparently located along the northern margin of the Mangani Graben. High manganese, zinc and lead (all over 1000 ppm), and in some cases arsenic and copper values occur in the same place as a very large SP gradient (60-100mV/20m). All SP values to the south of this zone are positive (most more than +100mV), while to the north many potentials are negative. VLF anomalies are located slightly further SE. The most likely cause of this anomaly is a completely unexposed lead/zinc vein along the northern margin of the Mangani Graben, with the VLF anomaly displaced slightly down-dip. A less likely cause might be stratiform mineralisation exposed at the fault boundary. Evidence for the possible presence of stratiform mineralisation in the Bukit Bulat area north of the Mangani Graben is based on the presence of a marked regional SP low, which fades away northwards, as well as mineral clasts in a fault zone which appear to consist of tuff impregnated by sulphides. The geochemimistry suggests that this mineralisation is mainly lead and zinc. Very little silver appears to be present in these soils samples, though this may be due to leaching.

b/ One other area has very large geochemical anomalies (maximum 6000 ppm Zn) located in a N-S zone to the west of the hill ridge. The largest of these anomalies is located between 240S 60W and 80S 40W. An SP low bounded by large gradients is located along this zone, and a second SP anomaly, though with lower associated geochemical anomalies lies 100m further west. Geophysical evidence suggests that these anomalies are caused by a mineral vein dipping west almost parallel to the hillside, though if it is more steeply dipping this will be much thicker than the vein marked on Enclosure 5. VLF anomalies are confused in this area, some being caused by boundary effects.

c/ Geophysical and geochemical evidence suggest that the Linda and Eloise Veins are part of the same mineral zone, though possibly locally disrupted by faulting. Usually this zone is best marked by a large SP gradient (>50mV/20m) over the hangingwall between a negative area west of the vein, and a positive area east of the vein. In some cases geochemical anomalies are large and narrow (400N 400E and 0N 320E), and sometimes consist of a broad zone with elevated element abundances. VLF anomlies are located in the same place as SP anomalies at 320N 320E over the Linda Vein outcrop, as well as over the anomalous zones at 160N,270E and 500N 380E which are assumed to be part of the same vein. In other places VLF anomalies over this vein zone are indistinct or absent, possibly caused by the discontinuous, brecciated nature of the mineralisation.

d/ It is not clear whether the Merah Selasa Vein joins with the Linda/Eloise Vein system, or if this is hosted in a more easterly fracture system. All of the area south of line 0 is anomalous for lead, zinc and manganese, and this area also contains a multitude of geophysical anomalies. The interpretation shown in Enclosure 5 was made with the aid of aerial photographs. It was assumed that lineaments were caused by faults, and that veins were displaced by these faults, or terminated against them. In the river the Merah Selasa Vein dips at a very shallow angle (30^{o}), almost parallel to the hillside. Large VLF, as well as geochemical and SP anomalies at 600S 160E may be caused by the footwall of the Merah Selasa Vein, but an aerial photograph lineament joining up with the Elose/Linda Vein system suggests that this might be a separate vein dipping more steeply.

e/ The mineralisation in the Reinier/Gorge/Gulley mineral zone causes relatively small anomalies compared to the anomalies further west. For this reason it is difficult to to see if this mineralisation continues for any distance, or what its trend is.

f/ In a number of cases isolated geochemical anomalies may be related to carbonaceous sediments of the Telisa Formation, as these contain disseminated lead and zinc sulphides near known veins or mineralised faults.

g/ In the north eastern part of the area arsenic anomalies, with no other associated elements, may be caused by the presence of disseminated arsenopyrite. In some cases these arsenic anomalies are associated with SP anomalies.

h/ An area of distinctly low metal abundances (most elements present at concentrations of less than 30 ppm) is marked on Enclosure 5, and seems to coincide with the higher parts of the hills, suggesting the presence of post-mineralisation tuff, resting on an irregular erosion surface.

i/ An area of consistently high element abundances (Pb and Zn higher than 300 ppm) is also marked on Enclosure 5. The cause of these high element abundances is not known, but may be caused by mineralised Telisa Formation sediments similar to those exposed east of the Eloise Vein. This whole area is associated with negative SP potential. A number of zones within this area associated with high SP gradients and the highest element abundances, as well as large VLF anomalies have been interpreted as veins or mineralised faults.

Enclosure 5 shows the geology of the area, as well as the location of the known mineralisation. The anomalous areas have been marked , with different symbols for the areas with different types of mineralisation (disseminated and vein mineralisation). This map is based on all the available evidence. Figure 122 shows the orientations of vein mineralisation as a series of profiles.

Chapter 6. Final conclusions of the investigation.

6.1 Comparison of Mangani with other Sumatran gold deposits.

Mangani is only one of a number of gold-silver deposits in Sumatra that were worked before the Second World War. A number of other deposits are known which were either uneconomic, or only worked briefly, or have never been evaluated. Figure 123 shows the locations of deposits which are discussed in the literature. The references relating to these deposits are listed in the bibliography at the end of this chapter.

The known gold occurrences are almost all located in the Barisan Mountain area, though in a number of cases placer deposits are located at some distance from the mountains. In addition local people pan gold from many of the rivers in the Barisan Mountains, e.g. near Muara Sipongi. The deposits marked in Figure 123 can be divided into a number of groups.

Most deposits are hosted in Tertiary volcanics, and are considered to be late Tertiary in age.

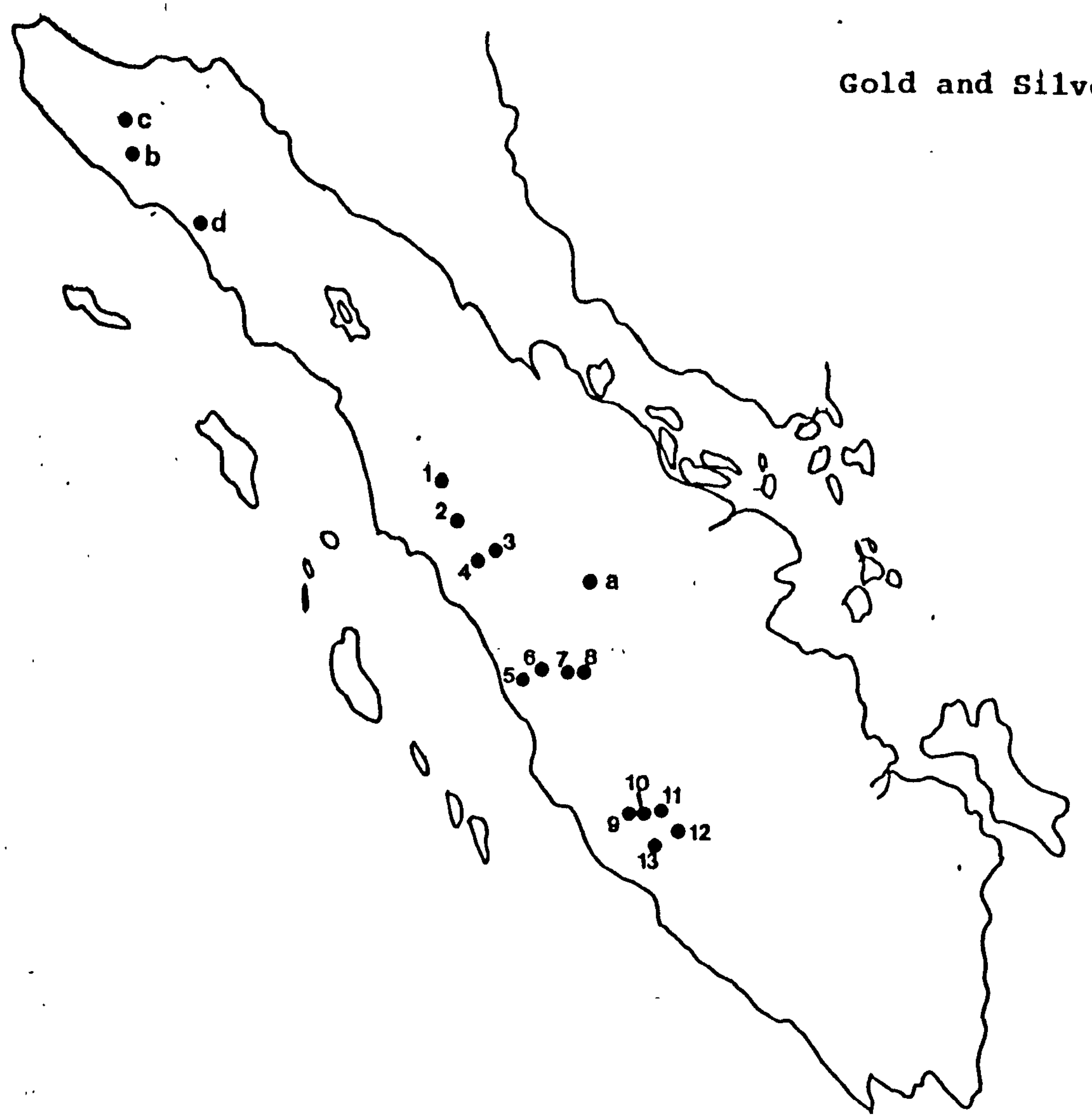
A number of areas contain gold mineralisation in quartz stringers in pre-Tertiary metamorphic rocks, e.g. Bulangsi (Boomgaart, 1941, 1947). The older gold deposits tend to be more common in the northern part of Sumatra, where placers are also more common.

The host rocks to most placer deposits have not been dated, though some are thought to be Tertiary, suggesting that the gold has been derived from pre-Tertiary deposits. However in some cases the host rocks to placers are Quaternary, suggesting that some of the Tertiary deposits have also been reworked.

A few examples of gold-bearing scarn deposits are also known from Sumatra, e.g. at Muara Sipongi (De Haan, 1950), and platinum is also known from the area (Hundeshagen, 1902). The age of such deposits is not usually known, though at Muara Sipongi Tertiary veins are also present.

Figure 123

Gold and Silver Mining areas in Sumatra



Alluvial deposits

a/ Bengkalis
b/ Meulaboh
(Woyla River)
(Meureuboh)
(Seunagan)
c/ Gajolands
d/ Tapaktuan

Primary deposits

1/ Muara Sipongi
2/ Kinadam
3/ Mangani
4/ Balimbing
5/ Salida
6/ Gunung Aroem
7/ Bulangsi
8/ Sungai Pagoe
9/ Lebong Tandai (Simau)
10/ Lebong Sulit
11/ Tambang Sawah
12/ Lebong Donok (M.M. Redjang Lebong)
13/ Lebong Simpang (M.M. Redjang Lebong)

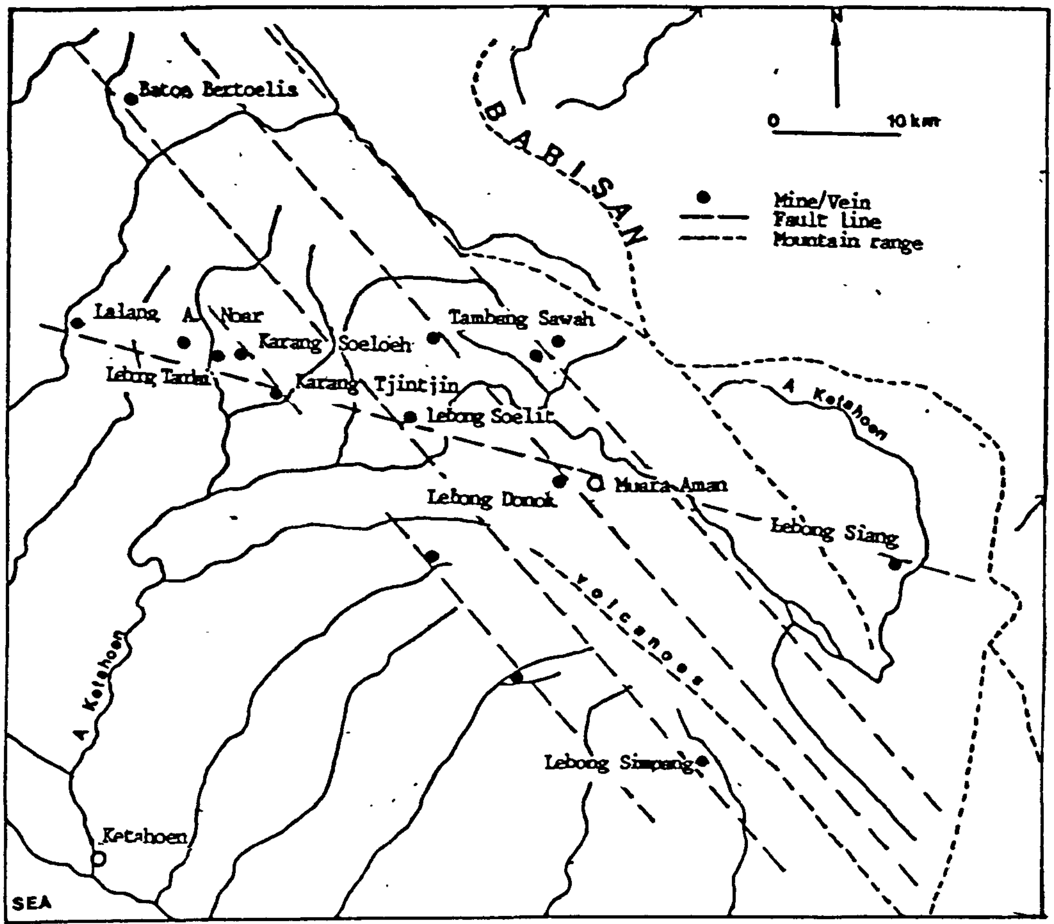
The Sumatran Tertiary veins have very similar geological and structural settings. All of these deposits are associated with intermediate to acidic Tertiary volcanics. In most of these areas rocks show extensive hydrothermal alteration. Not all of the deposits are located near granitic intrusions, but in this may be due to the erosional level. In many cases Tertiary limestones and mudstones are also present. It has previously been mentioned that there is a possibility that ophiolitic material may be present at Mangani, and at Sungai Pagoe serpentinites are also present.

Figure 124 shows the orientations of many of the Sumatran gold-silver veins. The most common orientations are N/S or NNE/SSW. Other vein trends include E/W, NE/SW and NW/SE. These trends all occur at Mangani (Chapter 2), either as fault or vein orientations. Some of the trends seen at Mangani can be directly related to movement along the SFS as described in Chapter 2, while other trends at Mangani have been interpreted as being caused by extensional movement related to the Mangani Graben. The N/S to NNE/SSW trending veins may have formed as a result of stress fields related to either movement type, though the dextral movement along faults and veins with this orientation at Mangani suggests that movement related to NW/SE extension has occurred.

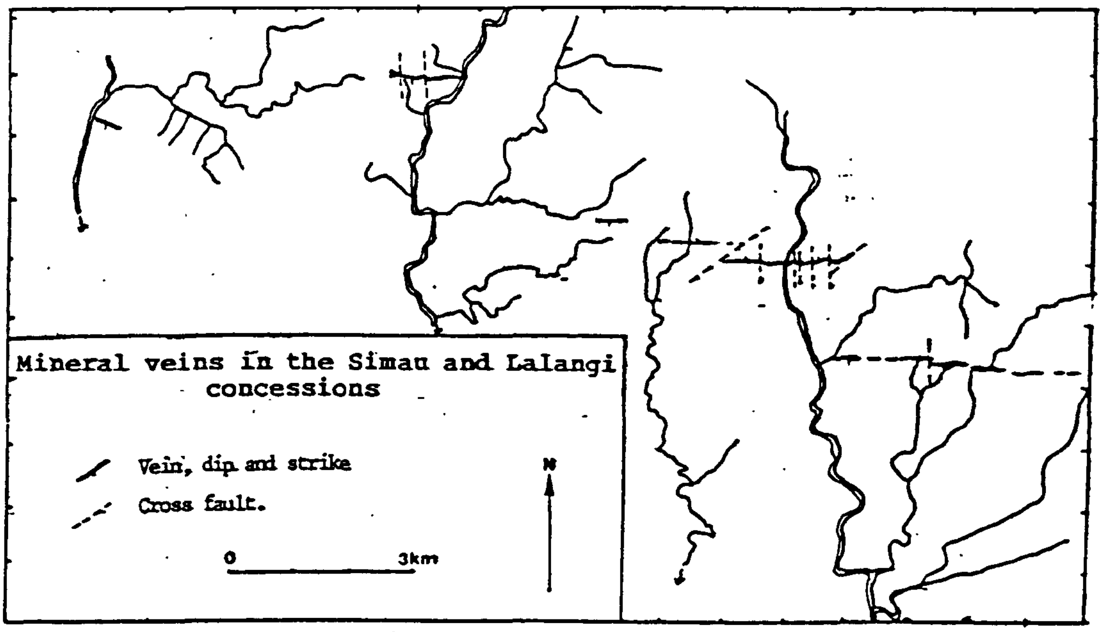
In the published accounts of a number of the Sumatran gold deposits graben structures are described, suggesting either that the entire Barisan area has been subjected to NW/SE extension, or that the location of gold deposits is related to the presence of local graben structures. Many of the deposits in the Benkulu area (Fig. 125a) are related to the Lebong Depression, which has a similar orientation to the Mangani Graben, but is larger (6km wide, extending for a length of 13km). At Mangani many of the veins occur outside the graben, though those to the north of the graben are not gold-bearing. In the Lebong area some of the veins outside the graban are gold-bearing, suggesting that the northern Mangani veins may contain precious metal at a different topographic level.

As stated previously most veins trend N/S, but where veins have a different orientation, they are often affected by faults with the same orientations as veins

Figure 124



After Aernout (1928)



(after Koolhoven and Aernout, 1928)

found in other areas. Figure 125 shows the vein and fault pattern seen in the Simau and Lalangi concessions in the Lebong area. Though veins trend E/W, they are affected by faults with a similar orientation to the faults hosting the veins at Mangani (N/S), and with a similar sense of displacement (dextral).

In many of the Sumatran gold deposits mineral deposition and faulting appear to have been contemporaneous, with breccia and ring-ores being common. It is considered that the faults not only acted as channels for hydrothermal fluids, as a result of the high permeability caused by the continual rebrecciation, but that pressure release after faulting resulted in the precipitation of minerals.

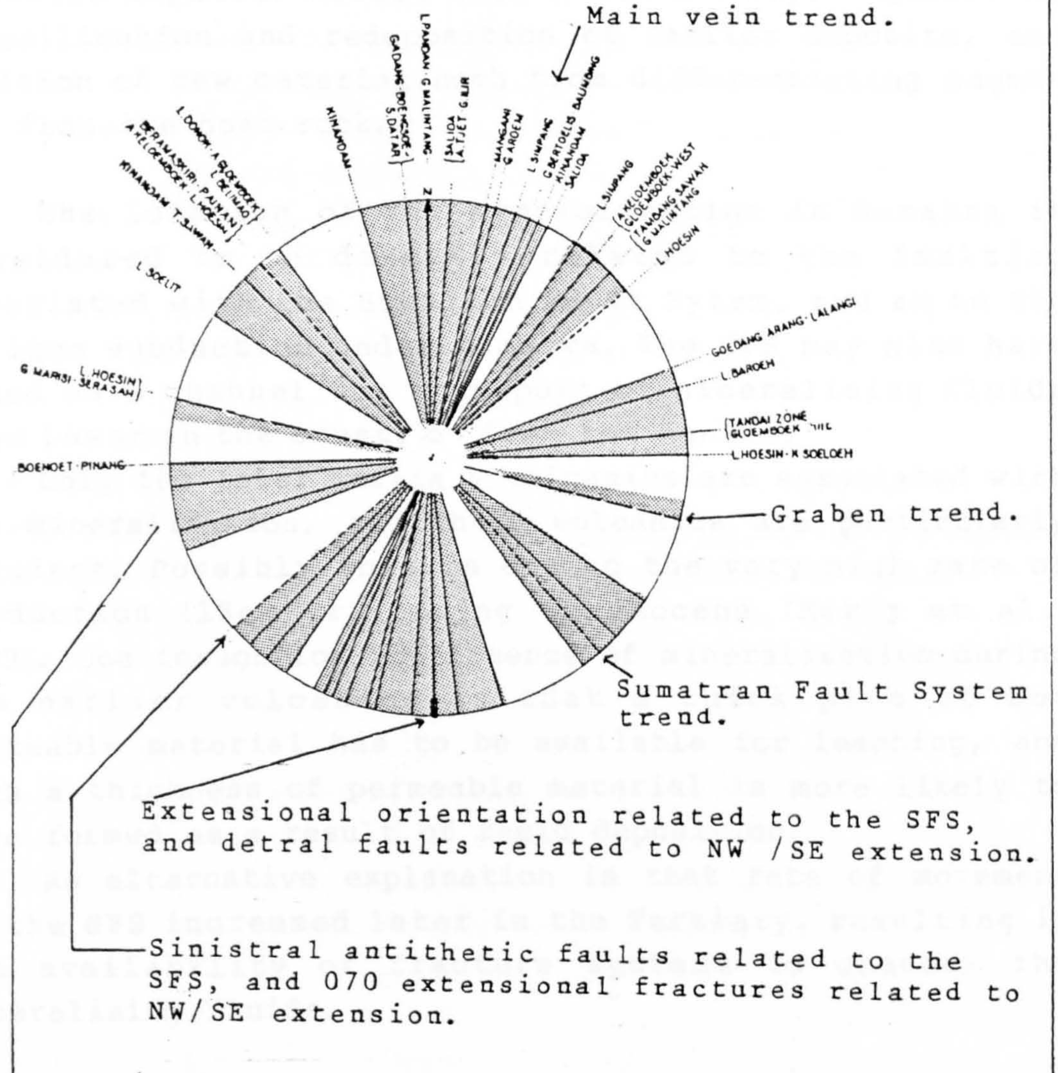
When the mineralogy of the different Sumatran gold veins is considered, many veins have a very high manganese content, which caused problems in the extraction of the silver as silver often occurred as an unknown compound (silver manganate?). Some of the veins are tellurium-bearing, while others are selenium-bearing, and when both ore types are present in one vein they appear to be of different ages, though Aernout (1927) suggests that at the Salida mine these differences may also be due to vertical zonation. The presence of some of the elements such as tin and bismuth found at Mangani is not recorded from the other mines, though the extensive description of the Lebong Tandai ores by Schouten (1928), and the description of the Salida ores by Westerveld and Uytenboogardt (1948) suggests that the paragenetic sequence seen at the different mines is similar. Some of the Sumatran veins, like the veins at Mangani contained an appreciable base metal content.

The tellurium-bearing veins in Sumatra have analogues in may other parts of the world, e.g. Boulder County, Colorado (Kelly and Goddard, 1969).

Hutchison (1983) points out that porphyry copper deposits, epigenetic gold mineralisation and volcanogenic tin deposits all occur in the same tectonic setting, which may explain the tin content of some of the veins at Mangani. Tin, bismuth and silver all occur in the Bolivian tin-silver veins (Kelley and Turneaure, 1970), though at Mangani tunsten is conspicuously absent.

g

Figure 124. Oreintation of Sumatran gold-silver veins.



L. = Lebong

Selenium-gold mineralisation only appears to be common in Sumatra. This suggests that some of the factors affecting the Sumatran gold mineralisation must be common to volcanic arcs in general, but that in Sumatra some special factor is responsible for the selenium content of many of the deposits.

Possibly the diverse element associations seen in Sumatran deposits result from a multi-stage sequence of remobilisation and redeposition of earlier deposits, and addition of new material both from differentiating magmas and from the host rock.

The location of the mineralisation in Sumatra is considered to be directly related to the faulting associated with the Sumatran Fault Sytem, and so to the oblique subduction under Sumatra. The SFS may also have acted as a channel for transport of mineralising fluids from lower in the crust, or from the mantle.

Only the later Tertiary volcanics are associated with the mineralisation, and these volcanics are particularly abundant. Possibly this is due to the very high rate of subduction (18cm/yr) during the Eocene (Karig et al., 1979). One reason for the absence of mineralisation during the earlier volcanics is that a thick pile of hot permeable material has to be available for leaching, and such a thickness of permeable material is more likely to have formed as a result of rapid deposition.

An alternative explanation is that rate of movement on the SFS increased later in the Tertiary, resulting in the availability of fracture systems to channel the mineralising fluids.

The role of manganese in mobilising and depositing the metals is not entirely clear, as very high manganese concentrations only occur in some of the mines. There does not appear to have been any extensive investigation of the host rock alteration in other Sumatran gold deposits, but at Mangani the presence of manganese epidote suggests that the manganese in the veins has not been derived from the host rock. It is possible that manganese has been derived from ophiolitic material carried along faults.

6.2 Discussion of the achievements of this investigation.

In Chapter 1 a number of research objectives were proposed. It is considered that many of the questions raised in Chapter 1 have been answered, and a number of additional questions have been raised.

1/ Geological investigation.

Most accessible outcrop in the Mangani area has been examined, and though the common presence of faults along the streams investigated has made interpretation of the information gained more difficult, a detailed geological map has been produced. It had previously been known that both the Telisa and Sihapas Formations occurred in this area, but the details of the lithologies present were scarce. The nature of the Brani Conglomerate has also been clarified.

It had originally been hoped that the geophysical investigation would also be useful in elucidating the geology, but the physical characteristics of the different lithologies present were not sufficiently different for this to be possible. In addition there were so many faults in the area, that it was difficult to determine which of the faults were of significance.

2/ Location of mineralisation.

Detailed mapping has resulted in the discovery of a number of previously unknown veins. Detailed geochemical and geophysical investigation of the Bukit Bulat area has shown that some of the veins discovered in the streams have a strike length of several hundred metres. In addition an unexposed zone of lead-zinc mineralisation located along the northern edge of the Mangani Graben is considered to be present, and a number of other anomalous zones may be caused by other mineralisation.

3/ Investigation of the best methods for locating such mineralisation.

A number of methods were used to investigate the mineralisation. Stream sediment geochemistry has proved very effective in pinpointing areas of base metal mineralisation. Soil geochemistry was not as effective, probably because the sample spacing was not close enough.

It is considered that due to the high cost of delineating areas of interest using more closely spaced samples, soil sampling should only be used during the detailed investigation of small areas.

Closely spaced soil samples proved quite effective in delineating the lead-zinc mineralisation in the Bukit Bulat area.

SP proved the most effective of the geophysical methods in delineating the mineralised areas, and this method is also fast, does not need skilled operators, uses cheap portable equipment, and the equipment can often be repaired in the field.

VLF, though the data could be collected quickly and easily, was not very useful, as too many anomalies were produced, often only related to minor faults. In addition to the regular servicing periods, the VLF transmitter was sometimes inexplicably silent, causing confusion, as the reciever was thought to have broken down.

Turam results were not useful in investigating the mineralisation in this area, and as the equipment was very heavy, much time and effort was needed to obtain the data.

It is not entirely clear why the magnetic investigation did not produce very useful results. Some veins contained magnetic pyrrhotite, but only produced small anomalies. The common occurrence of magnetite in pan concentrates, suggests that some of the volcanics contained this material, and that there was insufficient magnetic contrast between the veins and the host rock. In addition magnetic storms occured during part of the survey, and may have masked the vein response.

Investigation of the Rambutan-Silver Vein area showed that none of the methods used were useful in delineating veins with only a low base metal content. It is considered that such veins can only be discovered by geological mapping, and investigated by trenching and drilling.

4/ Types of mineralisation present.

Three main types of vein mineralisation are considered to be present. 1/ Base metal rich, bismuth and tin-bearing veins occur to the north of the Mangani Graben. 2/ Banded gold-bearing quartz veins occur to the south of the graben, hosted in the Brani Conglomerate. 3/ In the graben area precious metal-bearing veins occur, often associated with kaolin zones. These are described in detail in Chapter 4. In addition small areas of carbonaceous mudstones with veinlets of pyrite and base metals have been discovered, but the extent is unknown.

5/ Mode of formation of the mineralisation.

Structural investigation of the area, combined with chemical and petrological investigation of vein material has suggested a number of factors which may have been responsible for the formation of the mineralisation. The most important factors are considered to be the continual faulting, which provided permeable channels for the mineralising fluids, and the availability of a thick pile of leachable volcanics. Sub-volcanic plutons may have provided both a heat source, and some of the metals. Many veins contain a high manganese content, and this element may have been instrumental in both mobilising and precipitating the metals.

Veins at Mangani are considered to have formed as epithermal deposits, as a result of mineralisation along active fault zones. In the Brani Conglomerate most veins formed as fissure filling deposits, but many veins in other lithologies formed as a result of total alteration of fault breccia. Fluid inclusions studies suggest that minerals were deposited from boiling fluids, with the presence of pre-vein tuffisite dykes indicating that gas rich material was initially more abundant.

Further investigation of fluid inclusions, electron microprobe investigation of the ores, and isotope studies, may provide evidence for some of the theories put forward.

6/ Comparison of Mangani with other Sumatran deposits.

Most published information relating to Sumatran gold deposits has been collected together. Many deposits occur in a similar geological and tectonic setting, as described in Section 6.1, allowing the characteristics of favourable sites for mineralisation be identified.

7/ Investigation of the relationship between the plate tectonic setting and the mineralisation in Sumatra.

As described in section 6.1, the location of the Sumatran gold deposits is considered to be directly related to the tectonic setting.

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APPENDIX A

Indonesian words used for topographic features and local names.

Air	Water, stream	(abbreviation:- A.)
Barat	West	
Batang	River (B.)	
Bukit	Hill (B.)	
Emas	Gold	
Gadang	Tall, Big	(Minangkabau language)
Gunung	Mountain (G.)	
Jalan	Road, Way, Path	
Kanan	Right	Locally river junctions are described as left and right when facing upstream. In most places river branches are conventionally described as left and right when facing downstream.
Kiri	Left	
Mas	Gold	
Merah	Red	
Perak	Silver	
Rumah	House	
Rumah Sakit	Hospital	
Serassah	Waterfall	(Minangkabau language)
Simpang	River branch	
Sungai	Stream (S.)	
Tambang	Mine	
Timur	East	
Tinggi	Tall, High	
Utara	North	

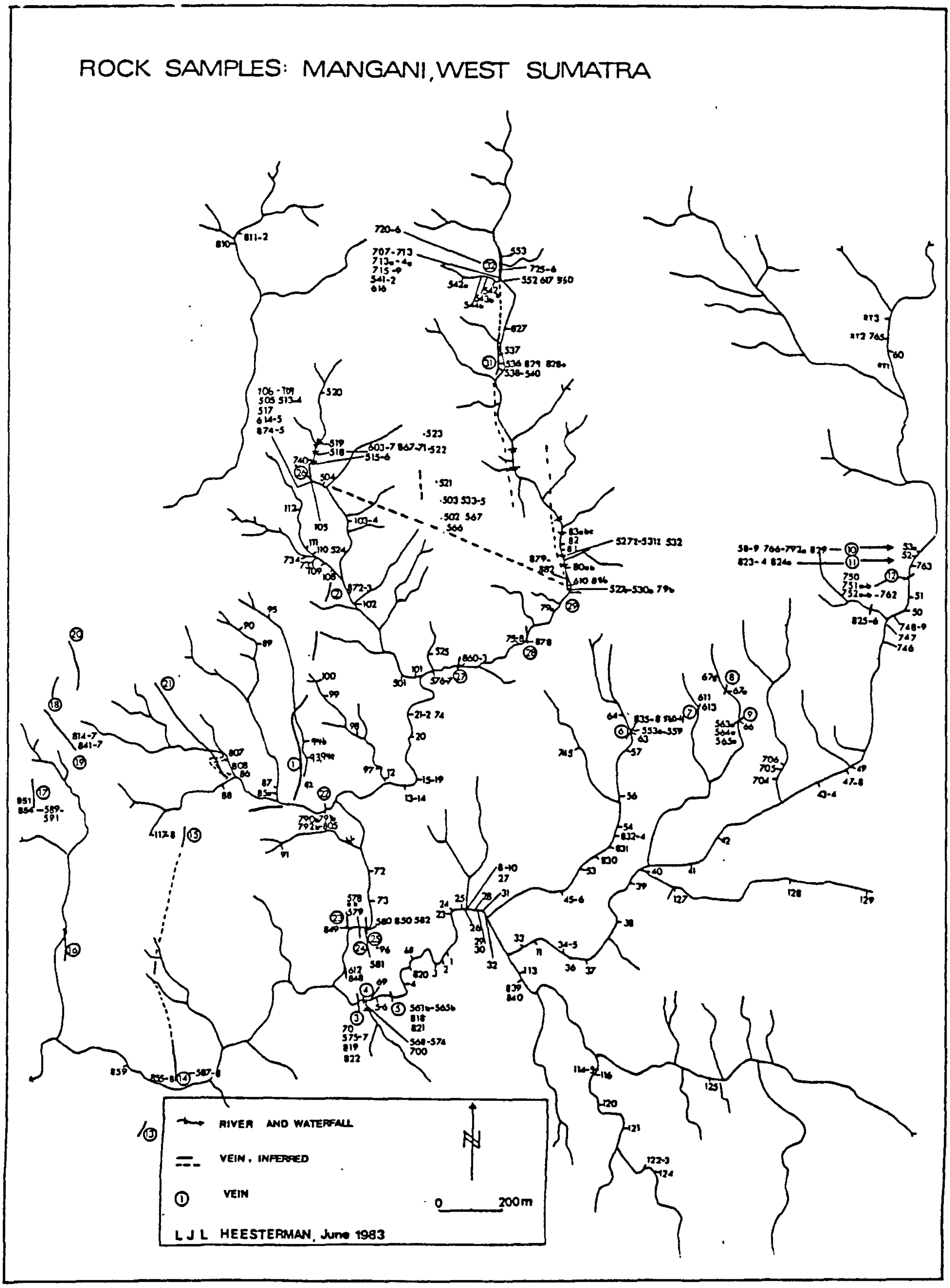
Spelling of the Indonesian language has changed since 1950, the main changes being:-

oe to u

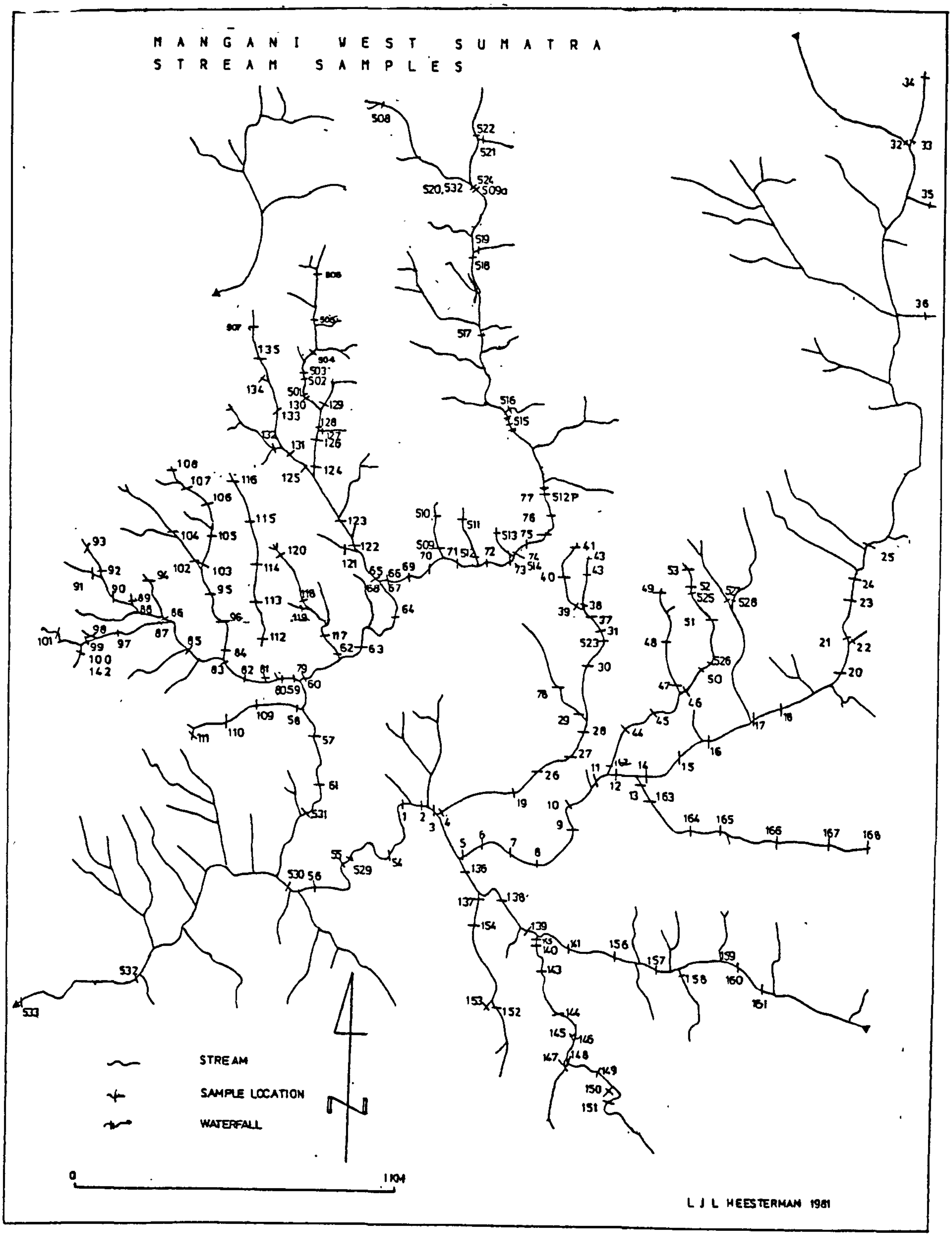
ij to y

Local names also seem to have many different officially recognised variations, e.g. Manggani.

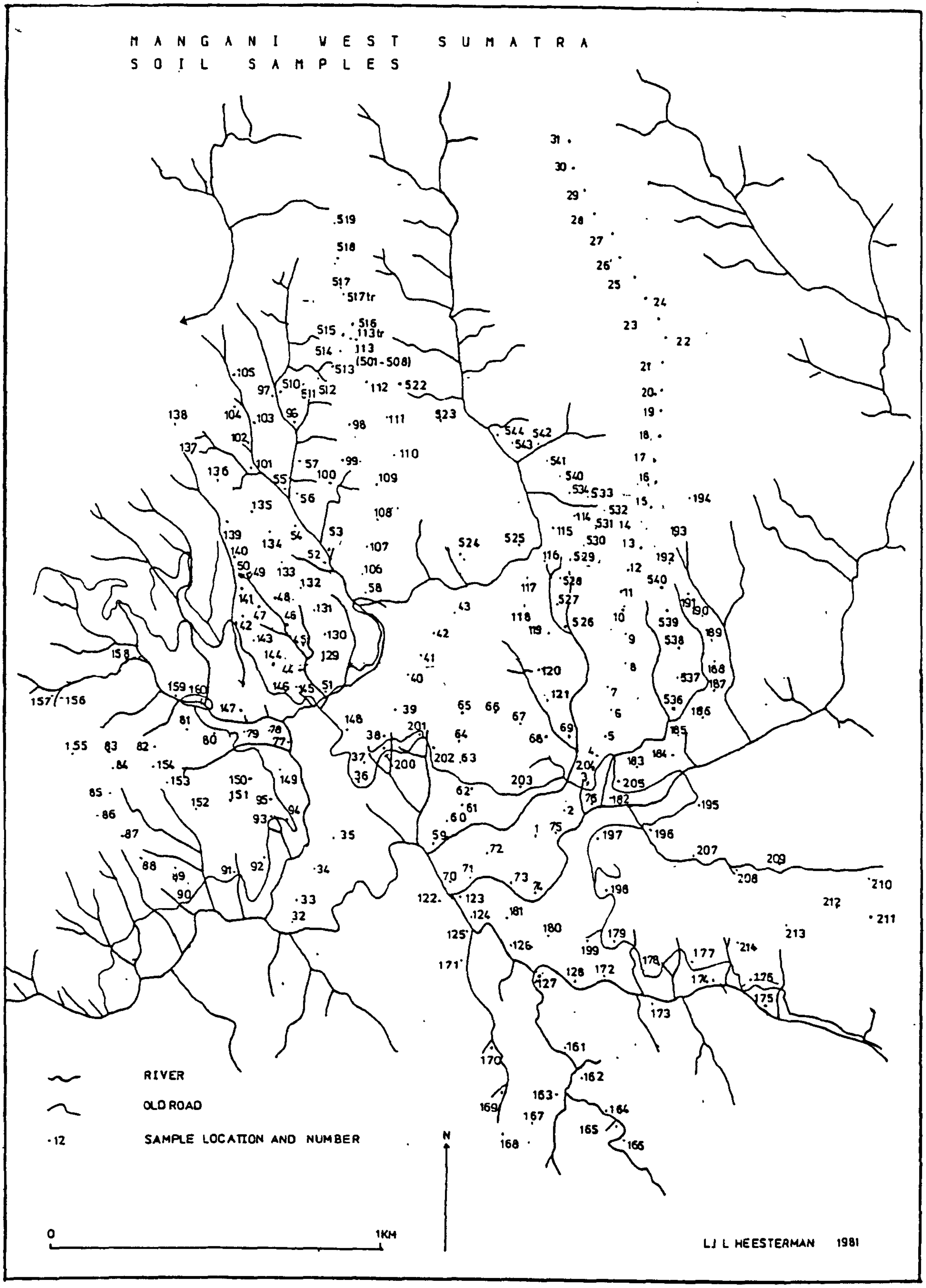
Appendix B.1


ROCK SAMPLES: MANGANI, WEST SUMATRA
RIVER AND WATERFALL
VEIN, INFERRED
VEIN
0
200m
L J L HEESTERMAN, June 1983

Appendix B.2


MANGANI WEST SUMATRA
STREAM SAMPLES
STREAM
SAMPLE LOCATION
WATERFALL
0
1KM
L J L HEESTERMAN 1981

Appendix B.3


MANGANI WEST SUMATRA
SOIL SAMPLES
RIVER
OLD ROAD
·12 SAMPLE LOCATION AND NUMBER
N
0
1KM
LJ L HEESTERMAN 1981

10123310 9

Appendix C

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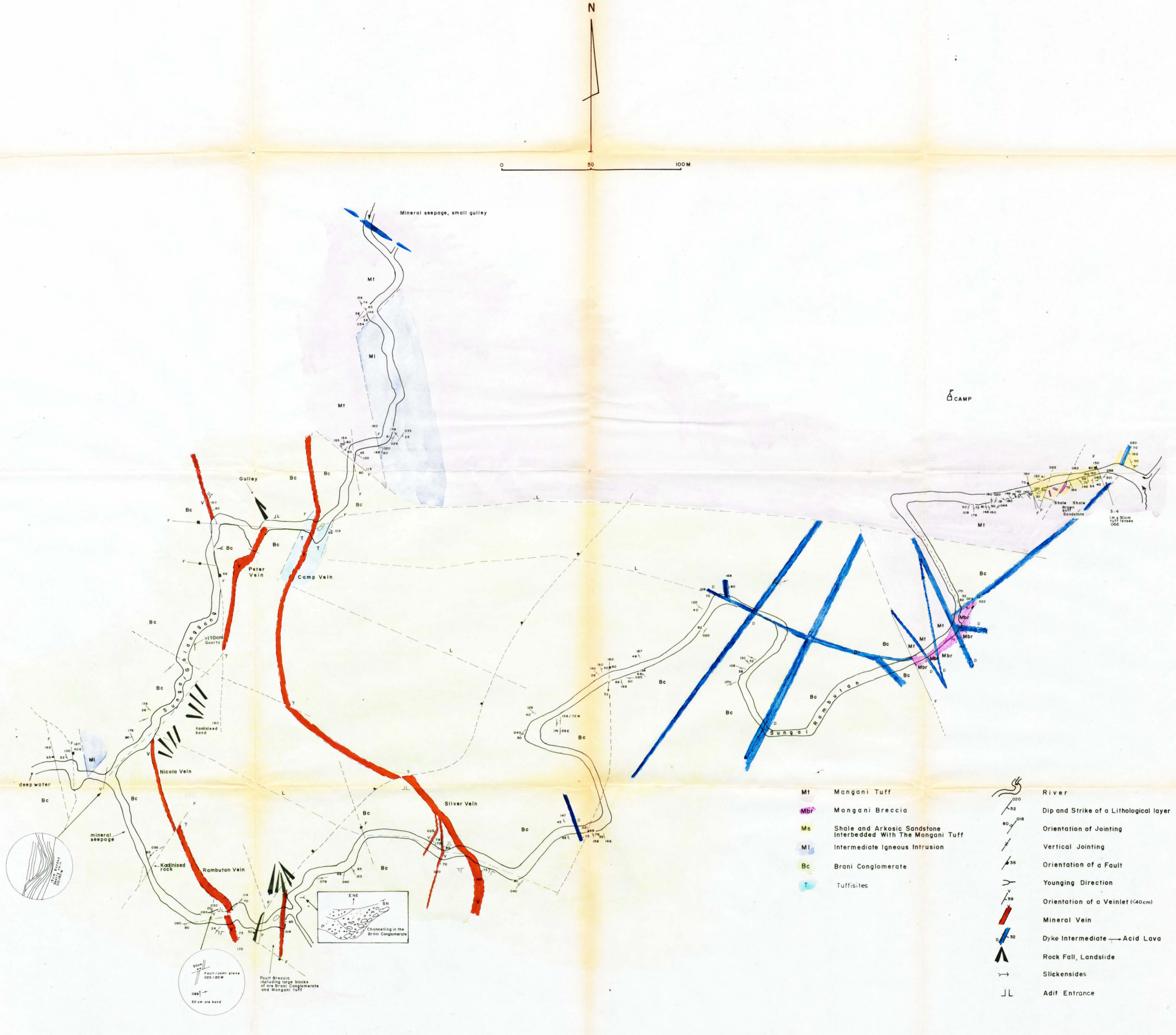
C THIS PROGRAM HAS BEEN WRITTEN IN STANDARD FORTRAN,AND USES THE GHOST
C GRAPHICAL OUTPUT SYSTEM AS IMPLEMENTED ON THE HARRIS 500 AT CHELSEA COLLEGE.
C GHOST CONSITS OF A SERIES OF GRAPHICS SUBROUTINES ORIGINALLY PRODUCED
C AT THE UKAEA CULHAM LABORATORY, AND CAN PRODUCE GRAPHICAL OUTPUT ON A
C LINEPRINTER, VDU OR GRAPH PLOTTER.
C     THIS PROGRAM CAN BE USED TO PLOT GEOCHEMICAL DATA AS CIRCLES
C     OF DIFFERENT SIZES AT EACH POINT TO WHICH A DISTANCE ALONG,
C     DISTANCE UP HAS BEEN PROVIDED.
C     DATA IS HELD IN A FILE CONNECTED TO CHANNEL 20, AS THE X AND Y
C     COORDINATES, AND PPM VALUES FOR EACH ELEMENT ANALYSED.
C     THE FORMAT STATEMENT MUST BE CHANGED FOR EACH DIFFERENT SET OF DATA
C     BUT DIFFERENT INTERVALS USED TO PLOT DIFFERENT SIZE CIRCLES
C     FOR EACH DATA SET CAN BE READ IN FROM ANOTHER DATA FILE.
C     ALL GRAPHICS OUTPUT IS CONTROLLED BY GHOST, BUT OUTPUT USED TO
C     CHECK THAT INFORMATION HAS BEEN INPUT CORRECTLY WILL GO TO
C     TO THE FILE CONNECTED TO CHANNEL 50.
      INTEGER TITLE(50),TITLE2(50)
      INTEGER AUTHOR(50)
      REAL MAX
      IN=20
      IOUT=50
      CALL PAPER(1)
      READ(IN,15)MAX
C     MAX IS THE MAXIMUM X OR Y COORDINATE, AND SHOULD OCCUR AS THE FIRST
C     ITEM IN THE FILE CONNECTED TO CHANNEL 20.
   15 FORMAT(F8.2)
      CALL MAP(0.0,MAX,0.0,MAX)
      READ(IN,10)NSAMP
C     NSAMP IS THE NUMBER OF SAMPLES TO BE PLOTTED, AND SHOULD BE THE
C     IN THE FILE CONNECTED TO CHANNEL 25
C     NEXT ITEM IN THE FILE CONNECTED TO CHANNEL 20.
   10 FORMAT(I4)
      READ(IN,11)TITLE
   11 FORMAT(50A1)
      READ(IN,11)TITLE2
      READ(IN,11)AUTHOR
C     TITLE, TITLE2 AND AUTHOR ARE THE NEXT THREE LINES OF THE FILE
C     CONNECTED TO CHANNEL 20. THESE ARE USED TO PLOT THE MAP TITLE, AREA
C     AND AUTHOR OF THE MAP.
C     EACH LINE OF TITLE AND TITLE 2 MUST NOT EXCEED 50 LETTERS.
      CALL PLOTCS(100.0,3900.0,TITLE,150)
      CALL PLOTCS(100.0,3700.0,TITLE2,150)
      CALL CTRMAG(5)
      CALL PLOTCS(100.0,100.0,AUTHOR,150)
      READ(IN,19)THRE1,THRE2,THRE3
C     THRE1-3 ARE THE BOUNDARY VALUES USED TO PLOT DIFFERENT SIZED SYMBOLS.
      WRITE(IOUT,19)THRE1,THRE2,THRE3
   19 FORMAT(3F7.1)
      IN=21
   99 CONTINUE
      II=II+1
      IF(II.EQ.NSAMP)GOTO 699
      READ(IN,20)XN,XY
C     XN IS THE DISTANCE ALONG, XY IS THE DISTANCE UP.
C     VAL IS THE AMOUNT TO BE PLOTTED.
      READ(99,27)VAL
   20 FORMAT(8X,2F9.2)
   27 FORMAT(40X,F10.2)
      WRITE(IOUT,29)XN,XY,VAL
   29 FORMAT(3F10.2)
C     XN IS THE DISTANCE ALONG,YN IS THE DISTANCE UP, VAL IS THE AMOUNT TO BE PLOTTED.
      IF(VAL.EQ.0.0)GOTO 99
      RADIUS=40.0
      IF(VAL.LE.THRE1) RADIUS=2.0
      CALL POSITN(XN,XY)
      IF(VAL.GT.THRE1.AND.VAL.LE.THRE2) RADIUS=8.0
      IF(VAL.GT.THRE2.AND.VAL.LE.THRE3) RADIUS=20.0
      CALL CIRCLE(RADIUS)
      GOTO 99
  699 CONTINUE
      CALL BORDER
      CALL GREND
      STOP
      END
EOT..
```

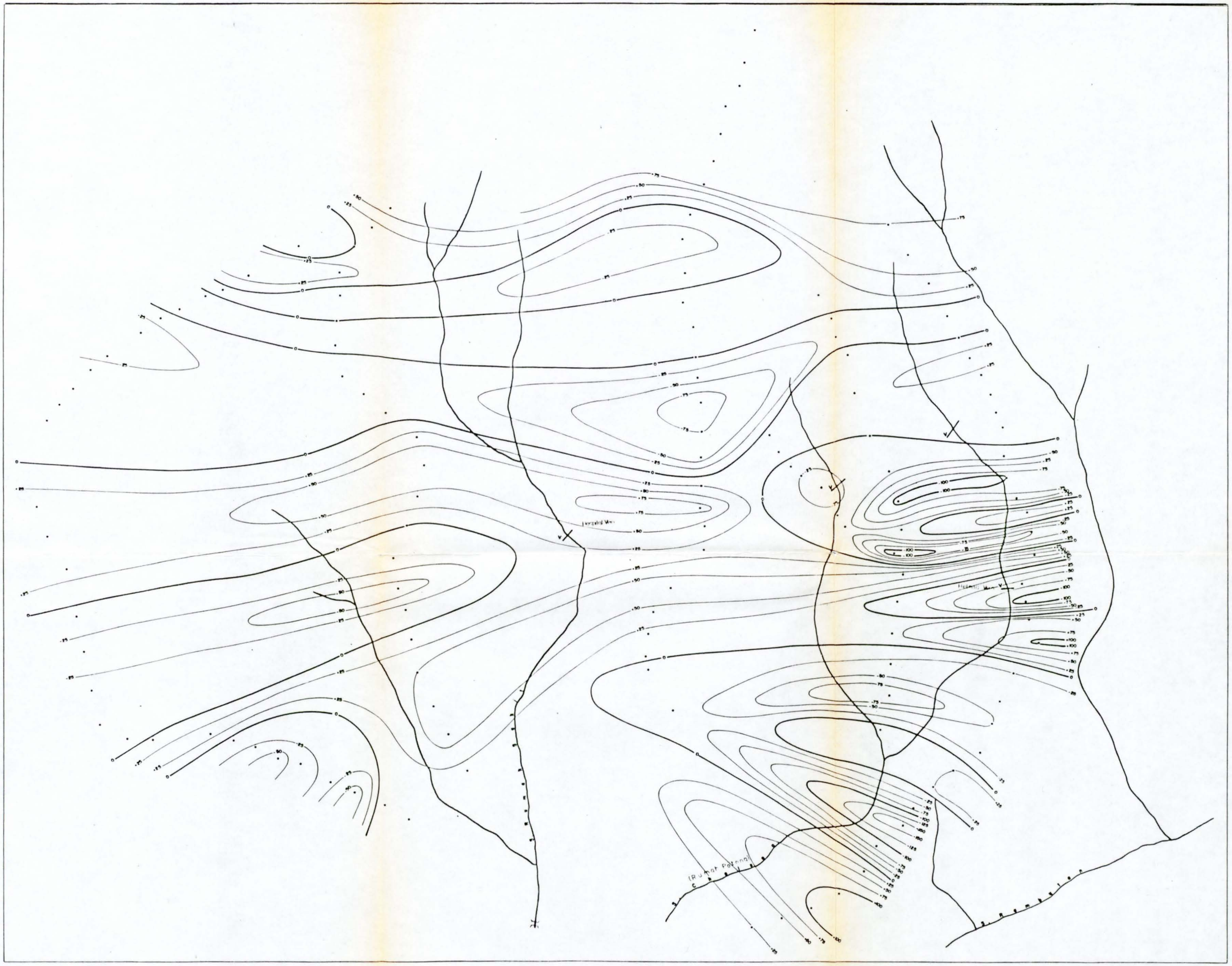
ENCLOSURE 3

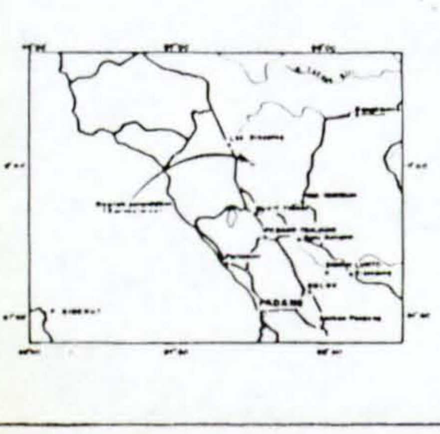
GEOLOGICAL MAP OF THE RAMBUTAN / SILVER VEIN AREA
MANGANI - WEST SUMATERA
INDONESIA



L J L HEESTERMAN 1982


GEOLOGICAL MAP OF THE MANGANI AREA
WEST SUMATRA, INDONESIA
ENCLOSURE 2
BUKIT BULAT
BUKIT GUNTUNG
Mangani Graben edge
S. RUMPUT PAIT
S. BOTUNG LAWAS
A. TAMBANG
A. MANGANI KANAN
A. MANGANI KIRI
S. GALANGGANG
S. RUMAH POTONG
S. RUMAH SAKIT
S. HAMBUTAN
S. BOTUNG
Start of the Brani HEP tunnels
Adit with red seepage
Banket Vein ?
red seepage
Kaolin band
Water sinks into stream bed
Start of MnO cementation of stream bed
Kaolinised tuff
Kaolinised tuff V?
Kaolinised tuff abundant disseminated sulphide red seepage
red seepage from soil
Kaolin bands
Gorge
Camp
Puar Datar
Gt Guntung acid tuff and breccia
Mc Mangani conglomerate, reworked Brani conglomerate and volcanics with interbedded tuff
Mt Mangani volcanic formation, basic to acid. characterised by red and green agglomerates
Ms Black mudstone, shale, volcano genic sandstone, interbedded with volcanics.
At Amas volcanic formation, basic to intermediate tuffs and lavas.
Ts Telisa formation. Carbonaceous mud and siltstones, sometimes calcareous.
Sc Sihapas formation, quartzconglomerates grading up into quartzite and siltstone
Bc Brani conglomerate, quartzite and phyllitic clasts with a haematitic matrix
?
I Microgranodiorite, granodiorite, Mangani porphyry
b Basaltic lava
a Andesitic lava
d Dacitic lava
t Tuffisite
Mb Mangani breccia, intrusive igneous breccia.
V Vein
D Dyke
L Aerial photo lineament
Adit enterence
Road bridge
F Fault
Lithological boundary
Dip and strike of bedding
Dip and strike of jointing
Younging direction
P Pyritised rocks
0
500m
L J L HEESTERMAN 1983





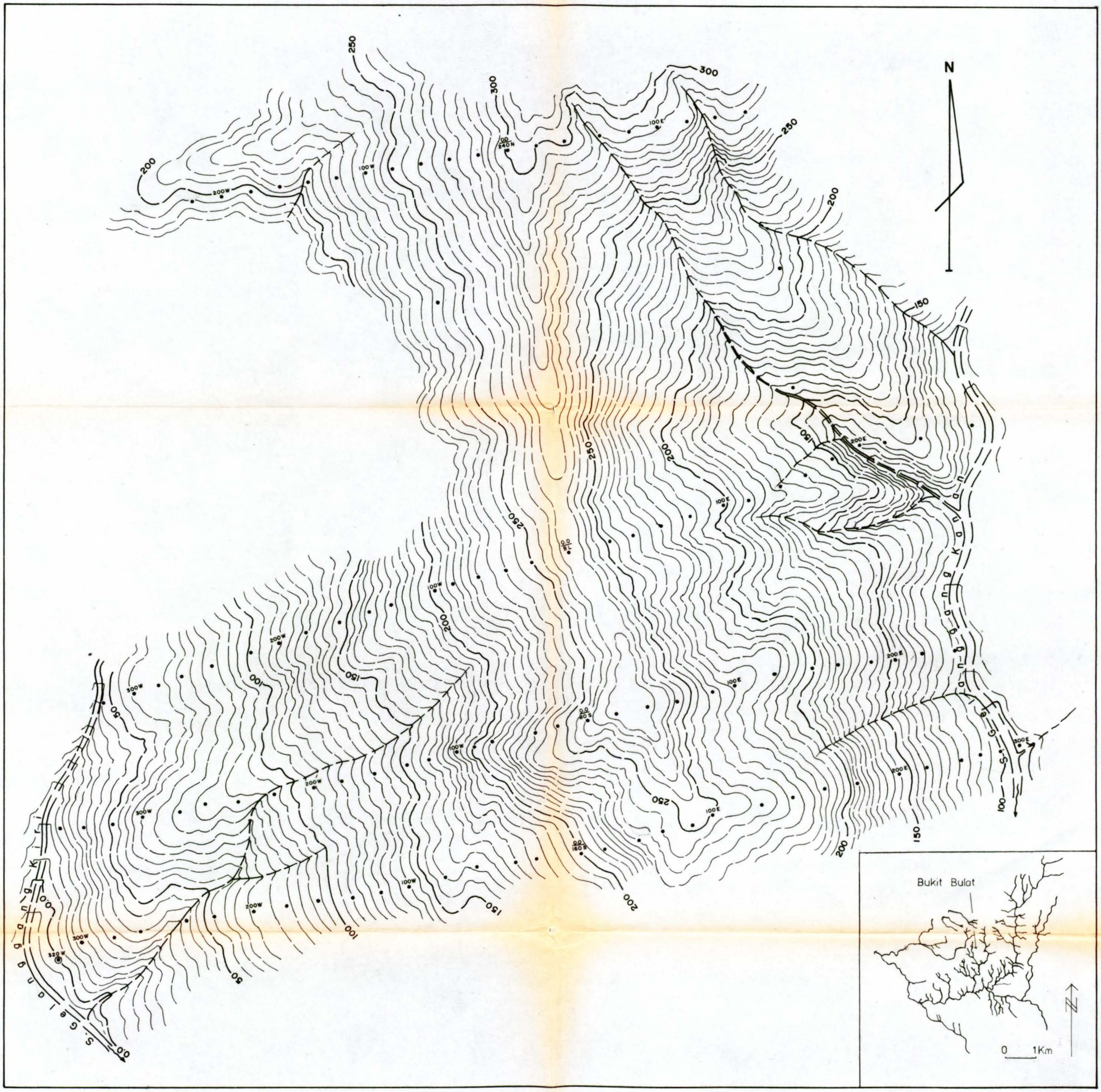
KETERANGAN (LEGEND)

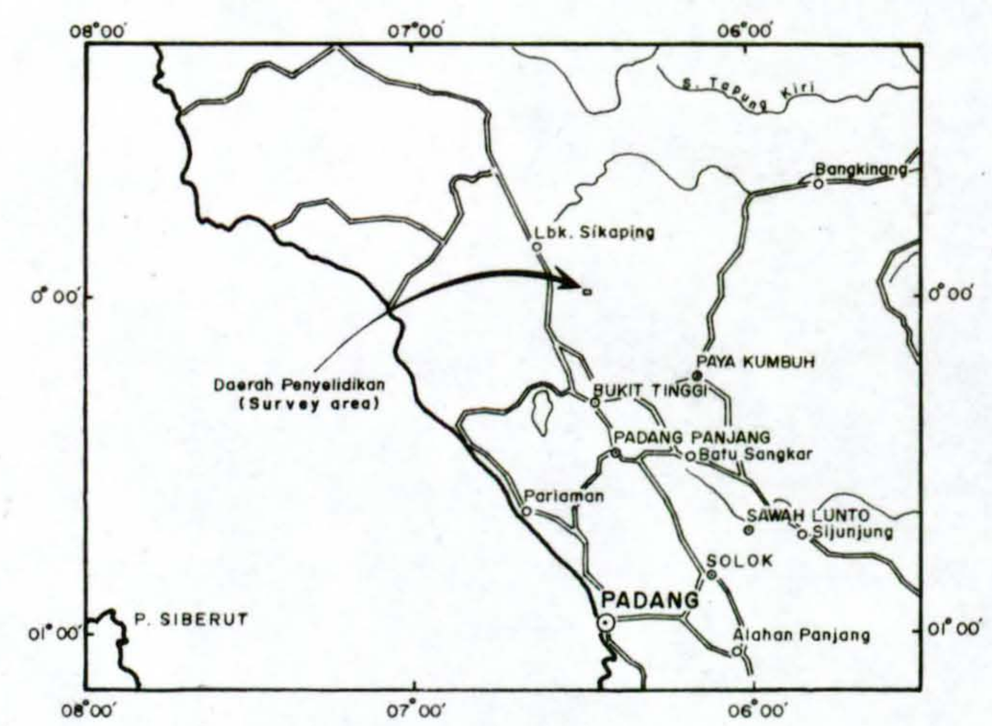
Sungai (river)

Kontur anomali setiap 25 Kc/S (Contour interval in 25 Kc/S)

Titik pengamatan (Station location)

DIRECTORATE OF MINERAL RESOURCES GEOPHYSICAL EXPLORATION DIVISION	
VLF ANOMALIES IN THE RUMAH SAKIT VEIN AREA - MANGANI WEST SUMATERA	1982
Compiler	[illegible]
Observer	[illegible]
Analyzer	[illegible]
Surveyor	[illegible]
Drafter	[illegible]
Operator	[illegible]
Validated	[illegible]
EGF Report nrs	Enclosure 4
Sheet of topographic map 83 Scale 1 : 40 000	





KETERANGAN:
(LEGEND)

Sungai
(River)

Garis sama tinggi setiap 5 meter
(Contour interval 5 meters)

100W Titik pengamatan
(Station location)

320W Titik yang dianggap ketinggiannya = 0.0 meter
(ketinggian lokal) - (Local elevation)

DIRECTORATE OF MINERAL RESOURCES
GEOPHYSICAL EXPLORATION DIVISION

TOPOGRAPHIC MAP
OF THE BUKIT BULAT AREA - MANGANI
WEST SUMATERA

Scale 0 40 80 120 M

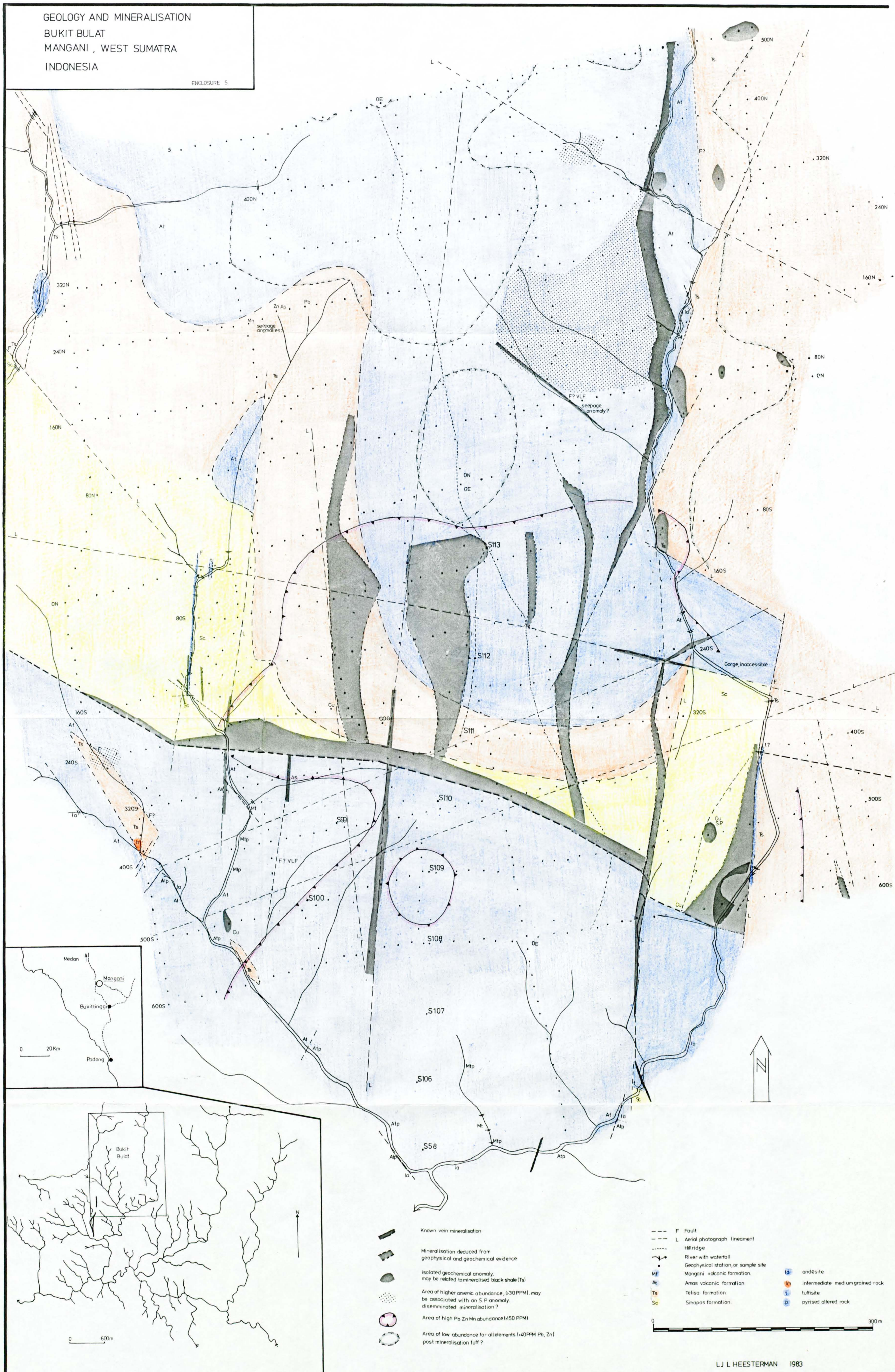
1981

Compiler	M.A.Muchlis, Adrian Z, L. Haesterman
Observer	P. Bangiel Eragie
Analyzer	P. Bangiel Eragie
Surveyor	P. Bangiel Eragie
Drafter	P. Bangiel Eragie
Operator	Budiman, Budi Gunardi
Validated	Ir. Hafny M. Noer

E.G.F. Report 076 Enclosure 1

Sheet of map 83 Scale 1:40.000

D



GEOLOGY AND MINERALISATION
BUKIT BULAT
MANGANI , WEST SUMATRA
INDONESIA
ENCLOSURE 5
seepage anomalies
F? VLF
seepage anomaly ?
Gorge, inaccessible
S113
S112
S111
S110
S109
S108
S107
S106
S100
S58
Medan
Mangani
Bukittinggi
Padang
20 Km
Bukit Bulat
600m
Known vein mineralisation
Mineralisation deduced from geophysical and geochemical evidence
isolated geochemical anomaly, may be related to mineralised black shale (Ts)
Area of higher arsenic abundance, (>30 PPM). may be associated with an S.P anomaly. disemminated mineralisation ?
Area of high Pb Zn Mn abundance (>150 PPM)
Area of low abundance for all elements (<40PPM Pb, Zn) post mineralisation tuff ?
F Fault
L Aerial photograph lineament
Hillridge
River with waterfall
Geophysical station, or sample site
Mt Mangani volcanic formation.
At Amas volcanic formation
Ts Telisa formation.
Sc Sihapas formation.
Ia andesite
Im intermediate medium grained rock
t tuffisite
p pyrised altered rock
0 300 m
LJ L HEESTERMAN 1983